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(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
20 February 2003 (20.02.2003)

PCT

(10) International Publication Number
WO 03/014545 A1

(51) International Patent Classification⁷: F01N 3/28, B28B 3/20

(21) International Application Number: PCT/IB02/03114

(22) International Filing Date: 8 August 2002 (08.08.2002)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
2001-241341 8 August 2001 (08.08.2001) JP

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(81) Designated States (*national*): CN, KR, US.

(84) Designated States (*regional*): European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, SK, TR).

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: EXHAUST GAS PURIFYING APPARATUS, PARTICULATE FILTER AND MANUFACTURING METHOD THEREOF

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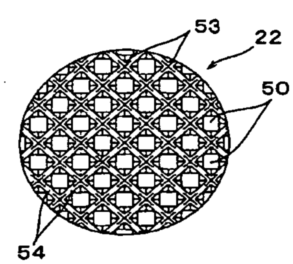

(57) **Abstract:** This invention relates to an exhaust gas purifying ap aratus having a particulate filter for collecting particulates in exhaust gas. This particulate filter (22) contains partition walls defining paths (50, 51) in wich exhaust gas flows. This partition wall is formed of porous material. This particulate filter (22) is created by gathering tips of the partition walls and then baking with the adjacent partition walls being in contact with each other. The adjacent partition walls are bonded together at a predetermined bonding strength if the partition walls are baked such that they are in contact. Alcording to this invention, the end portion of the particulate filter (22) has a higher strength than the predetermined bonding strength.

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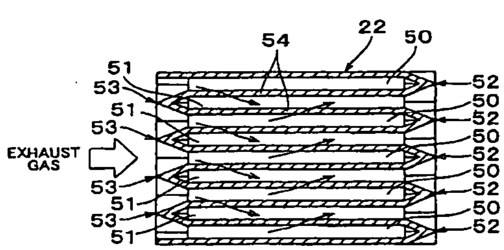

WO 03/014545 A1

EXHAUST GAS PURIFYING APPARATUS, PARTICULATE FILTER AND MANUFACTURING METHOD THEREOF

FIELD OF THE INVENTION

The invention relates to an exhaust gas purifying apparatus, particulate filter and manufacturing method thereof.

Background of the Invention

A particulate filter for collecting particulates in exhaust gas emitted from an internal combustion engine has been disclosed in published Japanese translation of PCT-application, JP-T-8-508199. In this particulate filter, a honeycomb structure is formed of porous material and some of a plurality of paths (hereinafter referred to as filter paths) in this honeycomb structure are closed at their upstream ends, while remaining filter paths are closed at their downstream ends. Consequently, exhaust gas flowing into the particulate filter always passes through porous walls (hereinafter referred to as filter partition walls) forming the filter paths and flows out of the particulate filter.

In this particulate filter, since exhaust gas always passes through the filter partition wall and after that, flows out of the particulate filter, its particulate collection rate is higher than the

particulate collection rate of a particulate filter in which exhaust gas only passes through the filter paths without passing through the partition walls of the particulate filter.

In the particulate filter disclosed in the above described publication, the filter path is closed by gathering the end portions of the filter partition walls and bonding together these end portions. Consequently, the exhaust gas flow-in opening in the filter path is shaped in a funnel. If the exhaust gas flow-in opening in the filter path is shaped in a funnel, exhaust gas flows into the filter path smoothly without a turbulent flow. That is, no turbulent flow is generated in exhaust gas when exhaust gas flows into the filter path. Thus, pressure loss of the particulate filter disclosed in the publication is low.

In the particulate filter of the above-described type, the filter path is completely closed by gathering the end portions of the filter partition walls such that the end portions are in contact with each other and baking the end portions being in contact with each other so as to bond together the end portions. Consequently, the filter path is completely closed. However, when the end portions that are in contact with each other are baked, these end portions are separated due to an

influence of thermal expansion of the end portions and surrounding filter partition walls, so that the filter path may not be completely closed.

Disclosure of the Invention

It is an object of the invention to close the filter path at its end portion securely in a particulate filter of the above-described type.

A first aspect of the invention relates to an exhaust gas purifying apparatus having a particulate filter for collecting particulates in exhaust gas. This particulate filter has a partition wall, which defines a path in which exhaust gas flows. Then, this partition wall is formed of porous material. This particulate filter is created by gathering tips of the partition walls such that adjacent partition walls are brought into contact with each other and baking them. Due to the fact that the partition walls are baked in a state where they are in contact with each other, the adjacent partition walls are bonded together at a predetermined bonding strength. Further, according to the first aspect of the invention, the end portion of the particulate filter has a higher bonding strength than the predetermined bonding strength.

The increased bonding strength can be achieved by a plurality of measures. It is important that the predetermined bonding strength is to be understood as the bonding strength which is achievable by the baked contact surface of end portions of adjacent wall plates bent towards each other.

A second aspect of the invention relates to a manufacturing method of a particulate filter for collecting particulates in exhaust gas. This method includes the steps of forming a preliminary formed body having partition walls defining a path by extruding porous material, closing the path of the preliminary formed body by gathering an end portion of the partition wall of the preliminary formed body so that tips of adjacent end portions are in contact with each other, baking the preliminary formed body, and reinforcing the closed portion in the path.

A third aspect of the invention relates to a manufacturing method of the particulate filter for collecting particulates in exhaust gas. This method includes the steps of forming a preliminary formed body having partition walls defining a path by extruding porous material, closing the path of the preliminary formed body by gathering an end portion of the partition wall of the preliminary formed body so that tips of

adjacent end portions are in contact with each other, baking the preliminary formed body, and loading the end portion of the partition wall closing the path of the preliminary formed body with a substance capable of oxidizing particulates.

A fourth aspect of the invention relates to an exhaust gas purifying apparatus having a particulate filter for collecting particulates in exhaust gas. An end portion of a path of the particulate filter includes a bonding portion bonded together at a predetermined bonding strength when tips of adjacent partition walls formed of porous material defining the path are brought in contact and are baked. In the fourth aspect of the invention, an average pore diameter of the bonding portion is smaller than an average pore diameter of other partition wall than the end portion.

A fifth aspect of the invention relates to an exhaust gas purifying apparatus having a particulate filter for collecting particulates in exhaust gas. In the fifth aspect of the invention, adjacent partition walls are bonded together by baking over a predetermined length from the tip of the partition wall made of porous material defining a path of the particulate filter such that the adjacent partition walls are in contact with each other and the adjacent partition walls are boned in

parallel with each other on a bonded portion of the partition walls.

A sixth aspect of the invention relates to a particulate filter for collecting particulates in exhaust gas. This particulate filter includes a body portion formed with partition walls made of porous material defining a path in which the exhaust gas flows, and an end portion including a bonding portion bonded at a predetermined bonding strength when tips of the adjacent partition walls are in contact with each other and baked. In the sixth aspect of the invention, the end portion has a higher strength than the predetermined bonding strength.

A seventh aspect of the invention relates to a particulate filter for collecting particulates in exhaust gas. This particulate filter includes a body portion formed with partition walls made of porous material defining a path in which the exhaust gas flows, and an end portion including a bonding portion bonded at a predetermined bonding strength when tips of the adjacent partition walls are in contact with each other and baked. In the seventh aspect of the invention, an average pore diameter of the bonding portion is smaller than an average pore diameter of the partition wall of the body portion.

A eighth aspect of the invention relates to a particulate filter for collecting particulates in exhaust gas. This particulate filter includes a body portion formed with partition walls made of porous material defining a path in which the exhaust gas flows, and a bonding portion baked with tips of the adjacent partition walls being in contact with each other. In the eighth aspect of the invention, the bonding portion is formed by bonding such that the adjacent partition walls are in parallel with each other.

Brief Description of the Drawings

The foregoing and further objects, features and advantages of the invention will become apparent from the following description of preferred embodiments with reference to the accompanying drawings, wherein like numerals are used to represent like elements and wherein:

Figs. 1A, 1B are diagrams showing a particulate filter according to a first embodiment of the invention;

Figs. 2A, 2B are diagrams showing an upstream end portion and a downstream end portion of the particulate filter of the first embodiment;

Figs. 3A, 3B are diagrams showing an upstream end portion and a downstream end portion of a conventional particulate filter;

Fig. 4A is a front view showing a honeycomb structure;

Fig. 4B is a side view showing the honeycomb structure, reinforcement member and die;

Figs. 5A, 5B are diagrams showing the reinforcement member in Fig. 4B;

Figs. 6A, 6B are diagrams showing the die in Fig. 4B;

Fig. 7A is a diagram showing the particulate filter of the second embodiment;

Fig. 7B is a diagram showing the honeycomb structure and die of the second embodiment;

Figs. 8A, 8B are diagrams for explaining oxidation process of particulates;

Figs. 9A, 9C are diagrams for explaining deposition process of particulates; and

Fig. 10 is a diagram showing the relation between the amount of oxidation removable particulates and the temperature of the particulate filter.

Detailed Description of the Preferred Embodiments

Hereinafter, the first embodiment of the invention will be described with reference to the accompanying drawings. Fig. 1A is an end face diagram of the particulate filter and Fig. 1B is a longitudinal sectional view of the particulate filter. As shown in Figs. 1A, 1B, the particulate filter 22 has a honeycomb

structure, containing a plurality of exhaust gas paths extending in parallel. The exhaust gas path constituted by an exhaust gas flow-in path 50 whose downstream end opening is closed by a tapered wall (hereinafter referred to as downstream tapered wall) 52 and an exhaust gas flow-out path 51 whose upstream end opening is closed by a tapered wall (hereinafter referred to as upstream tapered wall) 53. Namely, some part of the exhaust gas flow path (exhaust gas flow path 50) is closed by the downstream tapered wall 52 at the downstream end thereof, while the remaining exhaust gas flow path (exhaust gas flow-out path 51) is closed by the upstream tapered wall 53 at the upstream end thereof.

The downstream tapered wall 52 is formed by gathering and connecting the downstream end partition portion of the partition wall, which defines the exhaust gas flow-in path 50 of the particulate filter 22. On the other hand, the upstream tapered wall 53 is formed by gathering and connecting the upstream end partition portion of the partition wall, which defines the exhaust gas flow-out path 51 of the particulate filter 22.

According to the present embodiment, the exhaust gas flow-in path 50 and the exhaust gas flow-out path 51 are arranged alternately through a thin partition wall 54. In other words, the exhaust gas flow-in paths 50 and

the exhaust gas flow-out paths 51 are constructed such that each exhaust gas flow-in path 50 is surrounded by four exhaust gas flow-out paths 51 while each exhaust gas flow-out path 51 is surrounded by four exhaust gas flow-in paths 50. That is, one exhaust gas flow path (exhaust gas flow-in path 50) of two adjacent exhaust gas flow paths, is closed completely by the downstream tapered wall 52 at the downstream end thereof while the other exhaust gas flow path (exhaust gas flow-out path 51) is closed completely by the upstream tapered wall 53 at the upstream end.

As shown in Figs. 2A, 2B, reinforcement members 55, 56 are attached to tips of these tapered walls 52, 53. These reinforcement members 55, 56 are attached to the tapered walls 52, 53 so as to cover at least the tips of, or the entire tapered walls 52, 53.

The particulate filter 22 is formed of, for example, porous material such as cordierite. Thus, exhaust gas flowing into the exhaust gas flow-in path 50 passes through the surrounding partition wall 54 as indicated by an arrow in Fig. 1B and flows into the adjacent exhaust gas flow-out path 51. Since the tapered walls 52, 53 are a part of the partition wall 54, these tapered walls 52, 53 are, of course, also formed of the same porous material as the partition wall 54. Further,

according to the present embodiment, since the reinforcement members 55, 56 are also formed of porous material, exhaust gas passes through the upstream tapered wall 53 and the reinforcement member 56 as indicated by an arrow in Fig. 2A and flows into the exhaust gas flow-out path 51 and as indicated by an arrow in Fig. 2B, passes through the downstream tapered wall 52 and the reinforcement member 55 and flows out.

The upstream tapered wall 53 is formed in a quadrangular pyramid shape in which the sectional area of the exhaust gas flow-out path 51 is gradually decreased as it approaches the upstream. Of course, the reinforcement member 56, which is attached so as to cover the upstream tapered wall 53, is also formed in a quadrangular pyramid shape which becomes narrower as it approaches the upstream. Thus, the upstream end of the exhaust gas flow-in path 50, formed by four surrounding upstream tapered walls 53 has a quadrangular pyramid shape in which the sectional area of the flow path is gradually increased toward the upstream. As a result, as compared to a case where an intake opening of the exhaust gas flow-in path is formed as shown in Fig. 3A, exhaust gas flows into the particulate filter more easily.

That is, in the particulate filter shown in Fig. 3A, the upstream end of the exhaust gas flow-out path is

closed by a plug 72. In this case, since part of exhaust gas collides with the plug 72 as indicated with a solid line, exhaust gas does not easily flow into the exhaust gas flow-in path. As a result, pressure loss of the particulate filter is increased. Further, since exhaust gas flowing into the exhaust gas flow-in path from near the plug 72 becomes turbulent in the vicinity of the inlet as indicated with a dotted line, it is more difficult for the exhaust gas to flow into the exhaust gas flow-in path. As a result, pressure loss of the particulate filter is further increased.

On the other hand, the particulate filter 22 of the present embodiment allows exhaust gas to flow into the exhaust gas flow-in path 50 without causing any turbulent flow in exhaust gas as shown in Fig. 2A. Thus, according to the present embodiment, exhaust gas can easily flow into the particulate filter 22. Therefore, the pressure loss of the particulate filter is small.

In the particulate filter shown in Figs. 3A, 3B, particulates in exhaust gas are easily deposited on the upstream end face of the plug 72 and the surface of the partition wall nearby. The reason for this is that exhaust gas collides with the plug 72 and exhaust gas becomes turbulent near the plug 72. However, in the particulate filter 22 of the present embodiment, the

upstream end face which exhaust gas strongly collides with does not exist, since the upstream tapered wall 53. Further, the reinforcement member 56 are quadrangular pyramid and exhaust gas does not become turbulent near the upstream end face. Therefore, according to the present embodiment, a great number of particulates are not deposited on the upstream end region of the particulate filter 22, so that the pressure loss of the particulate filter 22 is suppressed.

On the other hand, the downstream tapered wall 52 of the present embodiment is formed in a quadrangular pyramid shape such that the sectional area of the flow path of the exhaust gas flow-in path 50 is gradually decreased as it approaches the downstream. Of course, the reinforcement member 55 attached so as to cover the downstream tapered wall 52 is also formed to be accommodated in a quadrangular pyramid shape which becomes narrower as it approaches the downstream. Thus, the downstream end of the exhaust gas flow-out path 51 formed by four surrounding downstream tapered walls 52 expands in a quadrangular pyramid shape in which the sectional area is gradually decreased as it approaches the downstream. As a result, exhaust gas easily flows out of the particulate filter as compared to a case where an exit opening of the exhaust gas flow-out path is formed as shown in Fig. 3B.

That is, in the particulate filter shown in Fig. 3B, the downstream end of the exhaust gas flow-in path is closed by a plug 70 and the exhaust gas flow-out path extends straight up to the exit. In this case, part of exhaust gas flowing out of the exit opening in the exhaust gas flow-out path flows along the downstream end face, so that a turbulent flow 71 is formed in the vicinity of the exit opening in the exhaust gas flow-out path. If a turbulent flow is formed in this way, exhaust gas does not easily flow out of the exhaust gas flow-out path.

On the other hand, in the particulate filter of the present embodiment, as shown in Fig. 2B, no turbulent flow is formed in exhaust gas, so that the exhaust gas can flow out of the exit opening of the exhaust gas flow-out path 51. Thus, according to the present embodiment, exhaust gas relatively easily flows out of the particulate filter. Therefore, the pressure loss of the particulate filter 22 is small.

In the meantime, the tapered walls 52, 53 and the reinforcement members 55, 56 may be formed in any other form than the quadrangular pyramid, for example, conical as long as it becomes gradually narrower as it approaches outside of the particulate filter 22.

Next, the reinforcement member of the first embodiment will be described in detail. The tapered walls 52, 53 of the particulate filter 22 of the above-described type are formed by gathering the partition walls which define the paths in the honeycomb structure made of porous material, that is, end portions of the partition walls 54 so that tips thereof are in contact with each other and baking the honeycomb structure. That is, the end portions of the partition walls are baked, so that the end portions are bonded together.

Actually, when the honeycomb structure is baked, a hole may be made in the tip of the tapered walls 52, 53 depending on a case, since the tips of the partition walls 54 are separated due to an influence of thermal expansion of the end portions of the partition walls. According to the present embodiment, since the basic configuration of the particulate filter 22 is that the end portions of the exhaust gas flow paths (exhaust gas flow-in path 50, exhaust gas flow-out path 51) are closed completely by the tapered walls 52, 53, the hole is not made in the tip of the tapered walls 52, 53 like this.

According to the present embodiment, before the honeycomb structure is baked, the reinforcement members 55, 56 are disposed at the tips of the tapered walls 52,

53 and after that, the honeycomb structure is baked. While the tapered walls 52, 53 are formed by bonding together the tips of the separate partition walls 54, the reinforcement members 55, 56 are integrated members. Therefore, they hold the tips of the partition walls 54, which form the tapered walls 52, 53, so that they do not leave each other, when the honeycomb structure is baked.

According to the present embodiment, the bonding strength of the bonding region of the partition wall 54, which constructs the tapered walls 52, 53, is increased, thereby preventing a hole from being made in the tips of the tapered walls 52, 53.

The average pore diameter of each of the reinforcement members 55, 56 is determined by the degree of increase of the pressure loss of the entire particulate filter 22 when the reinforcement members 55, 56 are attached to the tips of the tapered walls 52, 53 and the extent of reinforcement necessary for preventing any hole from being made in the tips of the tapered walls 52, 53. That is, a reinforcement member having a larger average pore diameter is used as the necessity of suppressing the increase of the pressure loss is larger. Then, a reinforcement member having a smaller average pore diameter is used as the level of reinforcement needs to be increased. In the meantime, the average pore

diameter of the reinforcement member in the present embodiment is smaller than the average pore diameter of the partition wall 54.

As a modification of the first embodiment, the reinforcement members 55, 56, particularly the tips thereof may be loaded with a substance capable of oxidizing particulates in exhaust gas. Consequently, the average pore diameter of the reinforcement members 55, 56 becomes smaller than a case where they are loaded with no substance capable of oxidizing particulates. Thus, even if a hole is made in the tip of the tapered walls 52, 53 when the honeycomb structure is baked, the average pore diameter of the tip of the reinforcement members 55, 56 is small. Therefore, the particulates in exhaust gas are prevented from flowing out of the particulate filter without being collected by the particulate filter.

Of course, if the hole in the tip of the tapered walls 52, 53 is closed by attaching the reinforcement members 55, 56 to the tapered walls 52, 53 after the honeycomb structure is baked, at least the object of the invention is achieved. In this case also, particulates in exhaust gas can be prevented from flowing out of the particulate filter 22 securely without being collected by the reinforcement members 55, 56 by reducing the average pore diameter of the reinforcement members 55, 56, which

are allowed to carry a substance capable of oxidizing the particulates.

In the meantime, it is important to construct the particulate filter 22 so that the pressure loss is latently small and keep the pressure loss from exceeding largely a latently achievable value during use of the particulate filter 22, in viewpoints of its performance.

That is, in case where an internal combustion engine is provided with a particulate filter, operation control of the internal combustion engine is so designed considering the latent pressure loss of the particulate filter. Even if the particulate filter is constructed so as to keep the pressure loss low, if the pressure loss exceeds its latently achievable value during use, the performance of the internal combustion engine is decreased.

Thus, according to the present embodiment, the partition wall which defines the upstream end region of the exhaust gas flow path in the particulate filter 22 is formed of a tapered wall and further, the reinforcement member covering this partition wall is formed also of a tapered member. Consequently, a turbulent flow is prevented when exhaust gas flows into the exhaust gas

flow path so as to keep the pressure loss of the particulate filter 22 latently low.

As described above, the partition wall which defines the upstream end region of the exhaust gas flow path in the particulate filter 22 is formed of the tapered wall and the reinforcement member covering this partition wall is formed of the tapered member. Therefore, particulates are not easily deposited on the wall of such tapered reinforcement member. That is, the particulates are prevented from being deposited on the wall of the tapered reinforcement member to produce a turbulent flow in exhaust gas flowing into the exhaust gas flow path during use of the particulate filter 22. As a result, the pressure loss can be prevented from being increased far beyond its latently achievable value during use of the particulate filter 22.

As described above, particulates are not easily deposited on the upstream reinforcement member 56 during use of the particulate filter 22. However, the particulates can be deposited on the upstream reinforcement member 56. In this case, the pressure loss is increased during use of the particulate filter 22.

Thus, according to the above-described modification of the embodiment of the invention, the upstream

reinforcement member 56 is loaded with a substance capable of oxidizing and removing particulates so as to oxidize and remove the particulates deposited on the upstream reinforcement member 56. As a result, since particulates collected by the upstream reinforcement member 56 are continuously oxidized and removed, no great number of the particulates are deposited on the upstream reinforcement member 56. Therefore, the pressure loss can be kept low during use of the particulate filter 22.

According to the present embodiment and its modification, a problem inherent to the structure of closing the exhaust gas flow-out path 51 that is, a problem that the pressure loss deviates from its achievable value during use of the particulate filter can be avoided by the upstream tapered wall 53 and the tapered reinforcement member 56 made of porous material in order to reduce the pressure loss of the particulate filter 22 latently,.

According to the modification of the present embodiment, a substance capable of oxidizing particulates is loaded on the entire particulate filter 22, that is, not only on the upstream reinforcement member 56, but also on the upstream tapered wall 53, the partition wall 54, the downstream tapered wall 52 and the downstream reinforcement member 55. Further, a substance capable of

oxidizing particulates is carried by not only the walls of the upstream reinforcement member 56, the upstream tapered wall 52, the partition wall 54, the downstream tapered wall 52, and the downstream reinforcement member 55, but also these pore walls inside. According to the modification of the present embodiment, the amount by a unit volume of the substance capable of oxidizing particulates loaded on the upstream reinforcement member 56 and the upstream tapered wall 53 is larger than the amount by a unit volume of the substance capable of oxidizing particulates loaded on the partition wall 54, the downstream tapered wall 52 and the downstream reinforcement member 55.

According to the present embodiment, although the upstream end opening and the downstream end opening of the particulate filter are closed completely, the concept of the invention can be applied to the particulate filter in which only any one of the upstream end opening and the downstream end opening is completely closed.

Next, a manufacturing method of a particulate filter of the present embodiment will be described briefly. First, a cylindrical honeycomb structure 80 is formed of porous material such as cordierite by extrusion as a preliminary formed body as shown in Figs. 4A, 4B. The honeycomb structure 80 has a plurality of exhaust gas

flow paths each having a square section. Part of these exhaust gas flow paths serves as the exhaust gas flow-in paths 50 in the particulate filter 22, while the remaining exhaust gas flow paths serves as the exhaust gas flow-out paths 51 in the particulate filter 22.

Next, a reinforcement member 81 made of porous material is disposed on each end face of the honeycomb structure 80 as shown in Fig. 4B. As shown in Fig. 5A, each reinforcement member 81 has a disc portion 82 fitting to a circular end face of the honeycomb structure 80. As shown in Fig. 5A, a plurality of leg portions 83 extends vertically from the disc portion 82. As shown in Fig. 5B, each of these leg portions 82 has a square of the square tube.

When the reinforcement member 81 is disposed on the end face upstream of the honeycomb structure 80, each leg portion 83 is accommodated in the exhaust gas flow-in path 50. On the other hand, when the reinforcement member 81 is disposed on the end face downstream of the honeycomb structure 80, each leg portion 83 is accommodated in the exhaust gas flow-out path 51. Fig. 5A indicates a sectional view taken along the lines 5A-5A in Fig 5B.

Next, a die 90 shown in Fig. 6 is pressed to the end face of the honeycomb structure 80 together with the reinforcement member 81. The die 90 is pressed to one end face of the honeycomb structure 80 and then to the other end face. Of course, it is permissible to prepare two dies 90 and press them to each end face of the honeycomb structure 80 at the same time.

As shown in Fig. 6A, the die 90 has a plurality of quadrangular pyramid shaped protrusions 91. Fig. 6B shows a protrusion 91. The die 90 is pressed to an end face of the honeycomb structure 80 together with the reinforcement member 81 such that the protrusions 91 are inserted into each predetermined exhaust gas flow path. When the protrusions 91 of the die 90 are inserted into predetermined exhaust gas flow paths, the disc portion 82 of the reinforcement member 81 is broken by these protrusions 91. If the die 90 is moved further toward the end face of the honeycomb structure 80, the disc portion 82 and the leg portion 83 of the reinforcement member 81 are gathered. At the same time, the partition walls 54, which form a predetermined exhaust gas flow path, are gathered so as to form the tapered walls 52, 53. Consequently, the predetermined exhaust gas flow paths are closed completely by the tapered walls 52, 53 covered by the reinforcement members 55, 56.

Next, the honeycomb structure 80 is dried, and then, the honeycomb structure 80 is baked. Next, the honeycomb structure is loaded with a substance capable of oxidizing particulates. As a result, the particulate filter 22 is formed.

As described above, the end portion of the particulate filter 22 is closed by the tapered walls 52, 53 composed of the same porous material as the partition wall 54. Therefore, the exhaust gas flow path (exhaust gas flow-in path 50, exhaust gas flow-out path 51) of the particulate filter 22 can be closed by the same material as the partition wall 54 according to such a simple method of pressing the die 90 against the end face of the honeycomb structure 80 as described above.

The step of disposing the reinforcement member 81 on the end face of the honeycomb structure 80 and pressing the die 90 against the end face of the honeycomb structure 80 may be executed after the honeycomb structure 80 is dried. Alternatively, it is permissible to soften the end portion of the honeycomb structure 80 after the honeycomb structure 80 is baked, then dispose the reinforcement member 81 on the end face of the honeycomb structure 80 and press the die 90 to the softened end portion. In this case, the end portion of the honeycomb structure 80 is baked again after that.

As a second modification of the present embodiment, a quadrangular pyramid shaped reinforcement member composed of porous material may be disposed directly on the tapered wall after the honeycomb structure 80 is baked.

Although the leg portion 83 of the reinforcement member 81 is means for positioning securely and holding the reinforcement member 81 on the honeycomb structure, the leg portion 83 may be eliminated if other means for achieving this is provided.

Next, the particulate filter of the second embodiment will be described. According to the second embodiment, as shown in Fig. 7A, the end portions of the partition walls 54 are bonded over a predetermined length from the tip so as to form extended portions 57, 58. In the downstream region of the particulate filter 22, the end portions downstream of the partition walls 54 are bonded together with adjacent parallel portions over a predetermined length toward the upstream from the tip so as to form an extended portion 57. On the other hand, in the upstream region of the particulate filter 22, the end portions upstream of the partition walls 54 are bonded together over a predetermined length toward downstream from the tip so as to form an extended portion 58.

As shown in Fig. 7B, these extended portions 57, 58 are formed by pressing the die 90 having the quadrangular pyramid shaped protrusions 91 and a rectangular portion 92 adjacent to this protrusion 91 and further containing a groove 93 between these rectangular portions 92 against each end face of the honeycomb structure 80.

Thus, according to the present embodiment, the bonding region of the end portions bonded together of the partition walls 54 in the end portion region of the particulate filter 22 is larger than the bonding region when only the tips of the partition walls are bonded together. For this reason, the bonding strength of the partition walls in the end portion region of the particulate filter 22 of the present embodiment is higher than the bonding strength when only the tips of the partition walls are bonded together.

As a modification of the second embodiment, the bonding strength of the end portions of the partition walls 54 which construct the extended portions 57 can be increased by loading on the extended portions 57, 58 with a substance capable of oxidizing the particulates. Of course, the entire particulate filter 22 may be loaded with the aforementioned substance capable of oxidizing the particulates.

In case of loading the honeycomb structure 80 with a substance capable of oxidizing particulates according to the present embodiment, the step of loading the honeycomb structure 80 with this substance capable of oxidizing particulate is carried out after the step of baking the honeycomb structure 80.

Next, the particulate filter 22 of the third embodiment will be described. The structure and operation of the particulate filter 22 of the third embodiment are the same as those of the first embodiment except the items described below. Therefore, description about the same structure and operation as the first embodiment is omitted.

According to the third embodiment, the reinforcement members 55, 56 of the first embodiment are omitted. According to the third embodiment, in place of them, the average pore diameter of the end portions of the partition walls 54 to be bonded together so as to form the tapered walls 52, 53 is set smaller than the average pore diameter of the partition wall 54.

According to the present embodiment, assuming a case where the areas of the end portions of the partition walls 54 bonded together are equal, the area of the end

portions of the partition walls 54 substantially being in contact with each other is larger than a bonding region of tips in an end portions having the same average pore diameter as the partition wall 54. Therefore, the bonding strength of the partition walls in an end portion region of the particulate filter 22 of the present embodiment is higher than the bonding strength of a case where the end portions having the same pore density as the partition wall 54 are bonded to each other.

According to the present embodiment also, it is of course permissible to increase the bonding strength of the tips of the partition walls 54 by loading the end portions of the partition walls 54 bonded together with a substance capable of oxidizing the particulates.

According to the present embodiment, a step of reducing the average pore diameter of the end portions of the partition walls 54 to be bonded together may be executed between a step of closing the exhaust gas flow path in the honeycomb structure 80 with the end portions and a step of baking the honeycomb structure 80. A step of loading the honeycomb structure 80 with a substance capable of oxidizing the particulates may be carried out after a step of baking the honeycomb structure 80.

Next, a particulate filter of the fourth embodiment will be described. According to the present embodiment, the bonding strength of the tips of the end portions of the partition walls to be bondeded together is incresed in order to prevent the tips of the end portions of the partition walls, which compose the tapered wall, from being separated and producing a hole when the honeycomb structure is baked. That is, an object of the above-described embodiment is to prevent a hole from being made in the tip of the tapered wall.

The object of the fourth embodiment is to prevent exhaust gas from flowing out of a hole in the tip of the tapered wall by closing the hole made in the tip of the tapered wall in a simple way. More specifically, according to the fourth embodiment, a hole made in the tip of each of the tapered walls 52, 53 is closed by loading the tips of the tapered walls 52, 53 with a substance capable of oxidizing the particulates after the honeycomb structure 80 is baked.

Finally, a substance capable of oxidizing particulates loaded on the particulate filter 22 will be described in detail. According to the above-described embodiment, a carrier layer made of alumina and the like is formed on the peripheral wall face of each exhaust gas flow-in path 50 and the inside of the peripheral walls

and each exhaust gas flow-out path 51 i.e., both side surfaces and inside of each partition wall 54, both side surface and inside of the tapered walls 52, 53, and both side surfaces and inside of a reinforcement member if it is provided. Then, this carrier is loaded with noble metal catalyst and active oxygen discharging agent which if excessive oxygen exists, takes in and retains oxygen and if the concentration of oxygen decreases, releases the retained oxygen in the form of active oxygen. According to the above-described embodiments, this the substance capable of oxidizing the particulates is the active oxygen discharging agent.

According to the above-described embodiments, platinum Pt is used as noble metal catalyst and as active oxygen discharging agent, at least one selected from alkaline metals such as potassium K, sodium Na, lithium Li, cesium Cs, rubidium Rb, alkaline earth metals such as barium Ba, calcium Ca, strontium Sr, rare earth elements such as lanthanum La, yttrium Y, cerium Ce, transition metal such as iron Fe, and carbon group element such as tin Sn is employed.

It is preferable to use alkaline metal or alkaline earth metal ensuring a higher ionization tendency than calcium Ca, such as potassium K, lithium Li, cesium Cs, rubidium Rb, barium Ba, and strontium Sr.

Next, an action for removing particulates from exhaust gas by means of the particulate filter 22 will be described about a case where platinum Pt and potassium K are loaded on a carrier. The same particulate removal action is carried out if other noble metals, alkaline metals, alkaline earth metals, rare earth elements, or transition metals are employed.

For example, if exhaust gas flowing into the particulate filter 22 is gas emitted from a compression ignition type internal combustion engine which burns with excessive air, exhaust gas flowing into the particulate filter 22 contains a great amount of excessive air. That is, if the ratio between air and fuel supplied into an intake air path and a fuel combustion chamber is referred to as air-fuel ratio of exhaust gas, the air-fuel ratio of exhaust gas in the compression ignition type internal combustion engine is lean. Further, since NO is generated in the fuel combustion chamber of the compression ignition type internal combustion engine, NO is contained in exhaust gas. Added to that, sulfur component S is contained in fuel and this sulfur component S reacts with oxygen in the fuel combustion chamber so as to produce SO_2. Therefore, SO_2 is contained in exhaust gas. Thus, exhaust gas containing

excessive oxygen, NO, and SO_2 flows into the exhaust gas flow-in path 50 of the particulate filter 22.

Figs. 8A, 8B show schematically an enlarged diagram of the surface of a carrier formed on an inner peripheral face of the exhaust gas flow-in path 50. In Figs. 8A, 8B, the particulate 60 is a particulate of platinum Pt and the active oxygen discharging agent 61 contains potassium K.

As described above, since exhaust gas contains a large amount of excessive oxygen, if exhaust gas flows into the exhaust gas flow-in path 50 in the particulate filter 22, oxygen O_2 adheres to the surface of platinum Pt 60 in the form of O_2 or O^{2-}. On the other hand, NO in exhaust gas reacts with O_2^- or O^{2-} on the surface of platinum Pt 60 so as to produce NO_2 ($2NO + O_2 \rightarrow 2NO_2$). Part of NO_2 generated next is oxidized on platinum Pt 60 and absorbed into the active oxygen discharging agent 61 and then combined with potassium K so that it is diffused into the active oxygen discharging agent 61 in the form of nitrate ion NO_3^- and produces potassium nitrate KNO_3.

On the other hand, SO_2 is contained in exhaust gas as described above and this SO_2 is absorbed in the active oxygen discharging agent 61 in the same mechanism as NO. That is, as described above, oxygen O_2 adheres to the

surface of platinum Pt 60 in the form of O_2^- or O^{2-} and SO_2 in exhaust gas reacts with O_2^- or O^{2-} on the surface of platinum Pt 60 and turns to SO_3. Part of SO_3 generated next is oxidized on platinum Pt 60 and absorbed into the active oxygen discharging agent 61, so that it is combined with potassium K and diffused into the active oxygen discharging agent 61 in the form of sulfuric ion SO_4^{2-} so as to produce potassium sulfate K_2SO_4. As a result, potassium nitrate KNO_3 and potassium sulfate K_2SO_4 are generated.

On the other hand, particulates composed of mainly carbon C are generated in a combustion chamber and therefore, these particulates are contained in exhaust gas. When exhaust gas flows in the exhaust gas flow-in path 50 in the particulate filter 22 or flows from the exhaust gas flow-in path 50 to the exhaust gas flow-out path 51, these particulates 62 contained in exhaust gas come into contact with and adhere to the surface of a carrier, for example, the active oxygen discharging agent 61.

If particulates 62 adhere to the surface of the active oxygen discharging agent 61, the concentration of oxygen on the contact face between the particulates 62 and the active oxygen discharging agent 61 decreases. If the concentration of oxygen decreases, a difference in

the concentration of oxygen occurs between the contact face of the active oxygen discharging agent 61 and the active oxygen discharging agent 61 whose concentration of oxygen is higher, so that oxygen in the active oxygen discharging agent 61 tries to move toward the contact face between the particulates 62 and the active oxygen discharging agent 61. As a result, potassium nitrate KNO_3 formed in the active oxygen discharging agent 61 is decomposed to potassium K, oxygen O and NO. Oxygen O moves toward the contact face between the particulates 62 and the active oxygen discharging agent 61, while NO is discharged out of the active oxygen discharging agent 61. NO discharged out is oxidized on platinum Pt 60 downstream and absorbed into the active oxygen discharging agent 61 again.

In addition, potassium sulfate K_2SO_4 formed in the active oxygen discharging agent 61 is decomposed to potassium K, oxygen O, and SO_2. Oxygen O moves toward the contact face between the particulates 62 and the active oxygen discharging agent 61, while SO_2 is discharged out of the active oxygen discharging agent 61. SO_2 discharged out is oxidized on platinum Pt 60 downstream and absorbed into the active oxygen discharging agent 61 again. However, since potassium sulfate K_2SO_4 is stable and difficult to decompose,

potassium sulfate K_2SO_4 does not easily emit active oxygen than potassium nitrate KNO_3.

The active oxygen discharging agent 61 generates and discharges active oxygen also in a reaction process with oxygen when NO_x is absorbed in the form of nitrate ion NO_3^- as described above. Likewise, the active oxygen discharging agent 61 generates and discharges active oxygen in a reaction process with oxygen when SO_2 is absorbed in the form of sulfate ion SO_4^{2-}.

Oxygen O that moves toward the contact face between the particulates 62 and the active oxygen discharging agent 61 is oxygen which is generated by decomposing such compound as potassium nitrate KNO_3, potassium sulfate K_2SO_4. Oxygen O generated by decomposing the compound has a high energy and an extremely high activity. Thus, oxygen which moves toward the contact face between the particulates 62 and the active oxygen discharging agent 61 acts as active oxygen O. Likewise, oxygen generated in a reaction process between NO_x and oxygen in the active oxygen discharging agent 61 or in a reaction process between SO_2 and oxygen acts as active oxygen. If the active oxygen O are in contact with the particulates 62, the particulates 62 are oxidized without any luminous flame in a short time (several seconds to several tens minutes), so that the particulates 62 are vanished

completely. Therefore, the particulates 62 are hardly deposited on the particulate filter 22.

Some type of the particulate filter is heated in red and burns the particulates with flame when particulates deposited in layers on the particulate filter are burned. The combustion with a flame does not continue unless a high temperature is kept. Therefore, the temperature of the particulate filter has to be kept high in order to continue combustion with the flame.

According to the embodiment of the invention, the particulates 62 are oxidized without any luminous flame as described above, and the surface of the particulate filter 22 is not heated in red. In other words, according to the embodiment of the invention, the particulates 62 are oxidized and removed under a relatively lower temperatures as compared to combustion with flame. Therefore, the particulate removal action by oxidation of particulates 62 without any luminous flame according to the embodiment of the invention is completely different from the particulate removal action by combustion with flame.

Since platinum Pt 60 and active oxygen discharging agent 61 are activated more as the temperature of the particulate filter 22 is increased, the amount of

oxidation removable particulates without luminous flame per unit time on the particulate filter 22 is increased as the temperature of the particulate filter 22 is increased.

A solid line in Fig. 10 indicates the amount G of oxidation removable particulates without luminous flame per unit time. The horizontal axis in Fig. 10 indicates the temperature TF of the particulate filter 22. Hereafter, the amount of particulates flowing into the particulate filter 22 per unit time is referred to as flow-in particulate amount M. If this flow-in particulate amount M is smaller than the oxidation removable particulates G i.e., within a region I in Fig. 10, all particulates flowing into the particulate filter 22 being contact with the particulate filter 22 are oxidized without any luminous flame on the particulate filter 22 in a short time (several seconds to several ten minutes) and removed.

Contrary to this, if the flow-in particulate amount M is larger than the oxidation removable particulate amount G i.e., within a region H in Fig. 10, the amount of active oxygen is not enough for oxidizing all particulates. Figs. 9A to 9C show the state of oxidation of particulates in such a case. That is, if the amount of active oxygen is short for oxidizing all particulates

and the particulates 62 adhere to the active oxygen discharging agent 61 as shown in Fig. 9A, only part of the particulates 62 is oxidized, while part of the particulates which is not oxidized sufficiently remains on the carrier. If the state in which the active oxygen amount is not enough continues, particulates which are not sufficiently oxidized remain on the carrier successively, so that as shown in Fig. 9B, the surface of the carrier is covered with remaining particulate portion 63.

If the surface of the carrier is covered with the remaining particulate portion 63, oxidation of NO and SO_2 by platinum Pt 60 and discharge of active oxygen by the active oxygen discharging agent 61 are eliminated, so that the remaining particulate portion 63 is left without being oxidized and slightly after, other particulates are deposited successively on the remaining particulate portion 63 as shown in Fig. 9C. That is, the particulates are deposited in layers.

If the particulates are deposited in layers, the particulates 64 are never oxidized by active oxygen O and therefore, other particulates are deposited successively on the particulates 64. That is, if the state in which the flow-in particulate amount M is larger than the oxidation removable particulate amount G is continued,

particulates are deposited in layers on the particulate filter 22 and the deposited particulates cannot be ignited and burnt until the temperature of exhaust gas is raised high or the temperature of the particulate filter 22 is raised high.

In the region I of Fig. 10, particulates are oxidized on the particulate filter 22 without any luminous flame in a short time and in the region II of Fig. 10, particulates are deposited in layers on the particulate filter 22. Thus, the flow-in particulate amount M always needs to be smaller than the oxidation removable particulate amount G for the particulates not to be deposited in layers on the particulate filter 22.

As evident from Fig. 10, the particulate filter 22 used in the embodiments of the invention is capable of oxidizing particulates even if the temperature TF of the particulate filter 22 is quite low. Thus, the flow-in particulate amount M and the temperature TF of the particulate filter 22 are kept so that the flow-in particulate amount M is always smaller than the oxidation removable particulate amount G.

If the flow-in particulate amount M is always smaller than the oxidation removable particulate amount

G, few particulates are deposited on the particulate filter 22, so that the back pressure is increased little.

On the other hand, if particulates are deposited in layers on the particulate filter 22 as described above, even if the flow-in particulate amount M becomes smaller than the oxidation removable particulate amount G, it is difficult to oxidize the particulates with active oxygen O. That is, if the flow-in particulate amount M becomes smaller than the oxidation removable particulate amount G when the particulates are deposited only below a predetermined level, this remaining particulate portion is oxidized without any luminous flame by the active oxygen O and removed.

If a case in which the particulate filter 22 is disposed in the exhaust gas path of an internal combustion engine and actually employed is considered, fuel and lubricant contain calcium Ca and therefore, calcium Ca is contained in exhaust gas. If SO_3 exists, this calcium Ca generates calcium sulfate $CaSO_4$. This calcium sulfate $CaSO_4$ is solid, which is not thermally decomposed even at a high temperature. Thus, if calcium sulfate $CaSO_4$ is generated and the pore in the particulate filter 22 is closed by this calcium sulfate $CaSO_4$, exhaust gas does not easily flow in the particulate filter 22.

In this case, if alkaline metal or alkaline earth metal having a higher ionization tendency than calcium Ca, for example, potassium K is employed as the active oxygen discharging agent 61, SO_3 diffused in the active oxygen discharging agent 61 is combined with potassium K so as to form potassium sulfate K_2SO_4. Calcium Ca passes through the partition wall 54 of the particulate filter 22 without being combined with SO_3 and flows out into the exhaust gas flow-out path 51. Thus, the pores in the particulate filter 22 are never clogged. Therefore, preferably, as the active oxygen discharging agent 61, alkaline metal or alkaline earth metal having a higher ionization tendency than calcium Ca i.e., potassium K, lithium Li, cesium Cs, rubidium Rb, barium Ba, or strontium Sr is employed.

The embodiments of the invention can be applied to a case where only noble metal such as platinum Pt 60 is loaded on the layer of a carrier formed on both side faces of the particulate filter 22. However, in this case, the solid line indicating the oxidation removable particulate amount G is moved slightly to the right as compared to the solid line shown in Fig. 10. In this case, active oxygen is discharged from NO_2 or SO_3 retained on the surface of the platinum Pt 60.

Further, it is permissible to employ a catalyst, which absorbs NO_2 or SO_3 as the active oxygen discharging agent and can discharge active oxygen from these absorbed NO_2 or SO_3.

Claims

1. An exhaust gas purifying apparatus comprising a particulate filter having: a partition wall made of porous material for defining a path allowing exhaust gas to flow; and an end portion in which an opening of the path is closed by a bonding portion bonded together at a predetermined bonding strength when tips of the partition walls gathered so that they contact each other are baked, for collecting particulates in exhaust gas, characterized in that

the end portion has a higher strength than the predetermined bonding strength.

2. An exhaust gas purifying apparatus comprising:
a particulate filter for collecting particulates in exhaust gas wherein

an end portion of a path of the particulate filter includes a bonding portion bonded together at a predetermined bonding strength when tips of adjacent partition walls formed of porous material defining the path are brought into contact and baked, and

the end portion has a higher strength than the predetermined bonding strength.

3. The exhaust gas purifying apparatus according to claim 1 or 2, further comprising:

a reinforcement member that reinforces the bonding portion provided at the end portion.

4. The exhaust gas purifying apparatus according to claim 3, wherein the reinforcement member is a member made of porous material, loaded with a substance capable of oxidizing the particulates.

5. The exhaust gas purifying apparatus according to claim 3, wherein an average pore diameter of the reinforcement member is smaller than an average pore diameter of the partition wall.

6. The exhaust gas purifying apparatus according to any one of claims 1 to 5, wherein the adjacent partition walls at the end portion are bonded together over a predetermined length from the tip of the partition wall.

7. The exhaust gas purifying apparatus according to claim 6, wherein the adjacent partition walls to be bonded together are parallel over the predetermined length from the tip of the partition wall.

8. The exhaust gas purifying apparatus according to any one of claims 1 to 7, wherein the tips of the adjacent partition walls are bonded together through a predetermined contact area and by increasing the contact

area per unit area of the tips at the bonding portion, the bonding strength of the end portion becomes higher than the predetermined bonding strength.

9 The exhaust gas purifying apparatus according to claim 8, wherein by decreasing an average pore diameter of the bonding portion, the contact area is increased.

10. The exhaust gas purifying apparatus according to claim 9, wherein by loading the bonding portion with a substance capable of oxidizing the particulates, the average pore diameter of the bonding portion is decreased.

11. The exhaust gas purifying apparatus according to claim 10, wherein the partition wall is loaded with a substance capable of oxidizing the particulates and the amount of substance loaded by the bonding portion is larger than the amount of the substance loaded on other portion of the partition wall than the bonding portion.

12. The exhaust gas purifying apparatus according to any one of claims 1 to 7, wherein the bonding portion is loaded with a substance capable of oxidizing the particulates.

13. The exhaust gas purifying apparatus according to any one of claims 1 to 12, wherein the particulate filter contains a plurality of paths and in part of the paths, downstream end portions of the partition walls defining the paths are gathered while in the remaining paths, upstream end portions defining the paths are gathered.

14. A manufacturing method of a particulate filter for collecting particulates in exhaust gas, comprising:

forming a preliminary formed body having partition walls defining a path by extruding porous material;

closing the path of the preliminary formed body by gathering an end portion of the partition wall of the preliminary formed body so that tips of adjacent end portions are in contact with each other;

baking the preliminary formed body; and

reinforcing the closed portion in the path.

15. The manufacturing method according to claim 14, wherein

the closed portion is reinforced by disposing a reinforcement member at the end portion of the partition walls of the preliminary formed body, gathering the tips of the partition walls of the preliminary formed body together with the reinforcement member, closing the path of the preliminary formed body by bringing the tips of

the end portions into contact with each other and baking the preliminary formed body and the reinforcement member.

16. The manufacturing method according to claim 14, wherein after the path of the preliminary formed body is closed, the closed portion is reinforced by providing the end portion with the reinforcement member.

17. The manufacturing method according to any one of claim 14 to 16, wherein the closed portion is reinforced by loading the tip of the partition wall with a substance capable of oxidizing particulates.

18. A manufacturing method of the particulate filter for collecting particulates in exhaust gas, comprising:

forming a preliminary formed body having partition walls defining a path by extruding porous material;

closing the path of the preliminary formed body by gathering an end portion of the partition wall of the preliminary formed body so that tips of adjacent end portions are in contact with each other;

baking the preliminary formed body; and

loading the end portion of the partition wall closing the path of the preliminary formed body with a substance capable of oxidizing particulates.

19. The manufacturing method according to any one of claims 14 to 18, further comprising a step of:

reducing an average pore diameter of the end portion of the partition wall closing the path in the preliminary formed body between closing the path and baking the preliminary formed body.

20. An exhaust gas purifying apparatus comprising: a particulate filter for collecting particulates in exhaust gas wherein

an end portion of a path of the particulate filter includes a bonding portion bonded together at a predetermined bonding strength when tips of adjacent partition walls formed of porous material defining the path are brought in contact and are baked, and an average pore diameter of the bonding portion is smaller than an average pore diameter of other partition wall than the end portion.

21. An exhaust gas purifying apparatus comprising: a particulate filter for collecting particulates in exhaust gas, wherein

adjacent partition walls are bonded together by baking over a predetermined length from a tip of the partition wall made of porous material defining a path of the particulate filter such that the adjacent partition walls are in contact with each other and the adjacent

partition walls are boned in parallel with each other on the bonded portion of the partition walls.

22. A particulate filter for collecting particulates in exhaust gas comprising:

a body portion formed with partition walls made of porous material defining a path in which the exhaust gas flows; and

an end portion including a bonding portion bonded at a predetermined bonding strength when tips of the adjacent partition walls are in contact with each other and baked, the end portion has a higher strength than the predetermined bonding strength.

23. A particulate filter for collecting particulates in exhaust gas comprising:

a body portion formed with partition walls made of porous material defining a path in which the exhaust gas flows; and

an end portion including a bonding portion bonded at a predetermined bonding strength when tips of the adjacent partition walls are in contact with each other and baked,

wherein an average pore diameter of the bonding portion is smaller than an average pore diameter of the partition wall of the body portion.

24. A particulate filter for collecting particulates in exhaust gas comprising:

a body portion formed with partition walls made of porous material defining a path in which the exhaust gas flows; and

a bonding portion baked with tips of the adjacent partition walls being in contact with each other,

wherein the bonding portion is formed by bonding such that the adjacent partition walls are in parallel with each other.

FIG. 1A

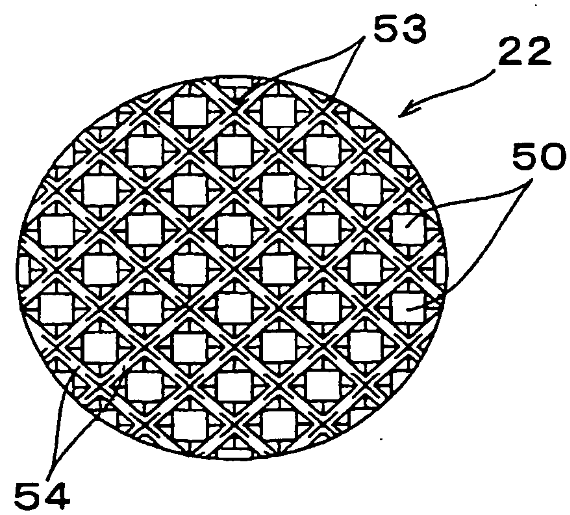
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FIG. 1B

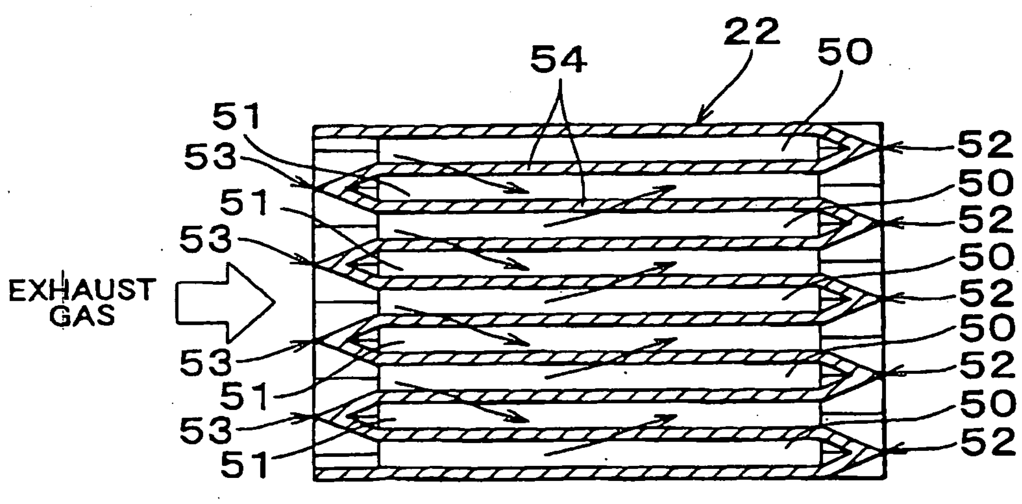
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FIG. 2A

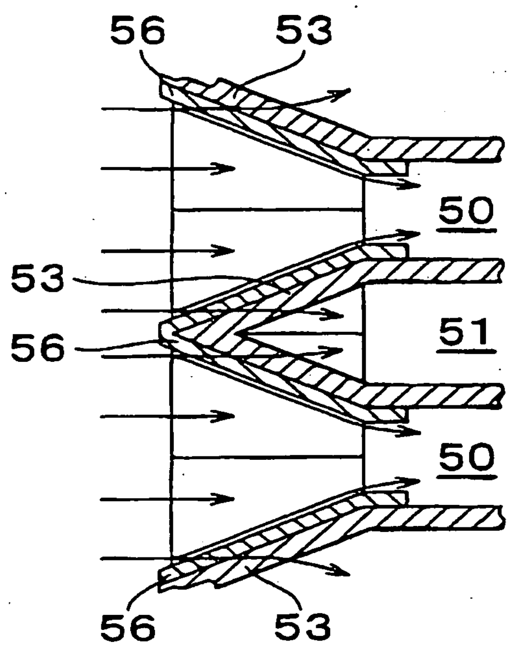

FIG. 2B

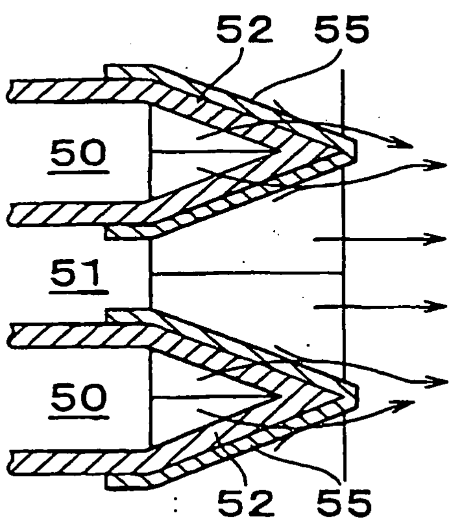

FIG. 3A

RELATED ART

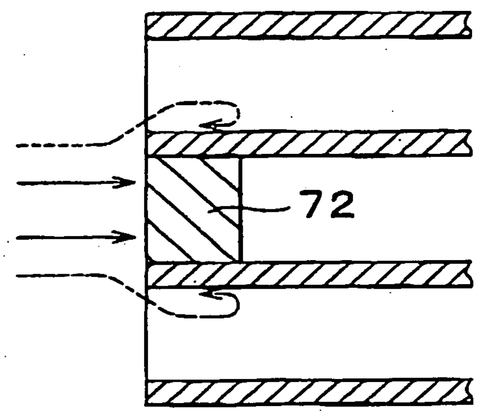

FIG. 3B

RELATED ART

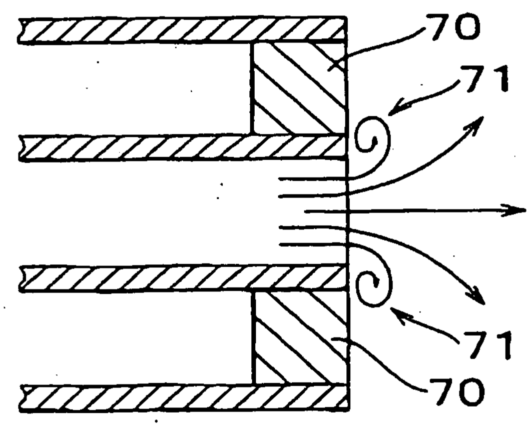

FIG. 4A

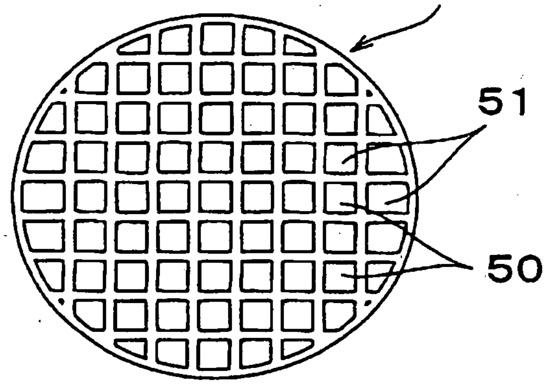

FIG. 4B

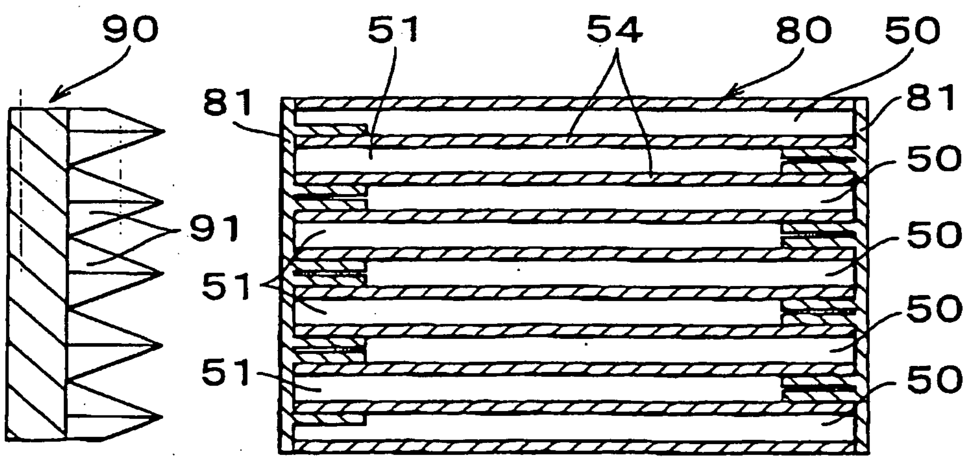

FIG. 5A

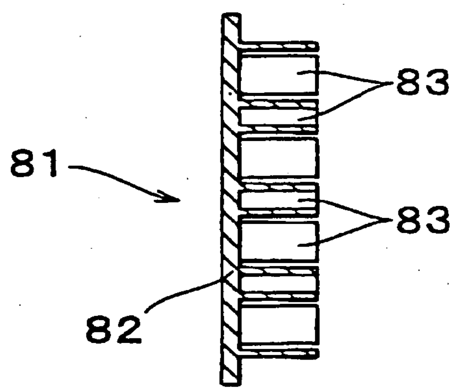

FIG. 5B

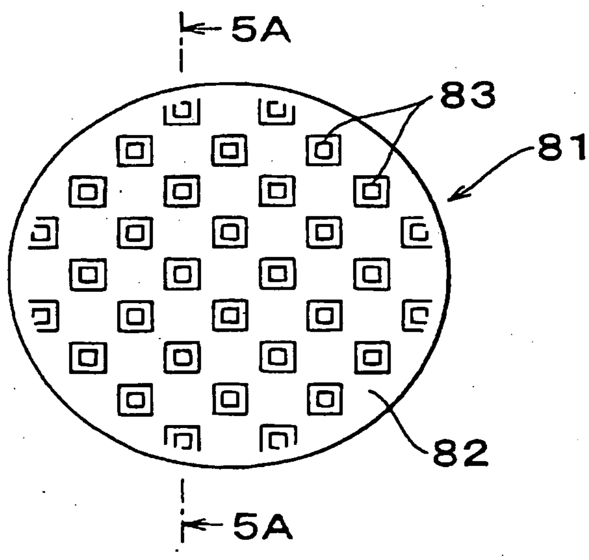

FIG. 6A

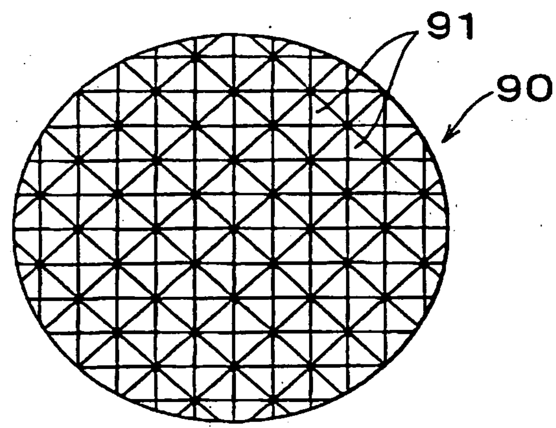

FIG. 6B

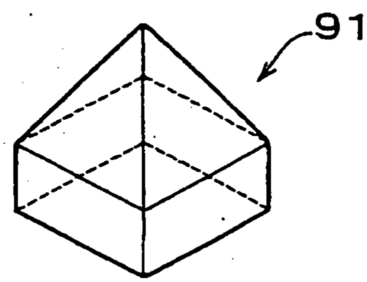

FIG. 7A

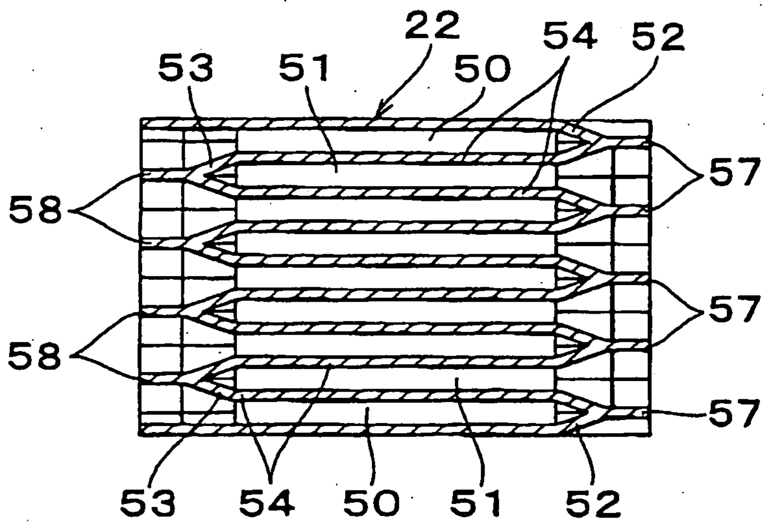
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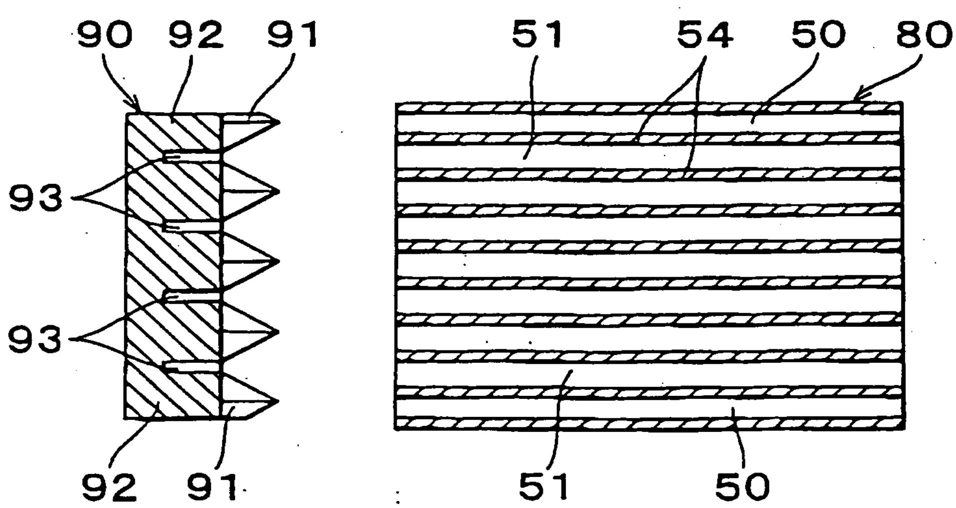
FIG. 7B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51
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FIG. 8A

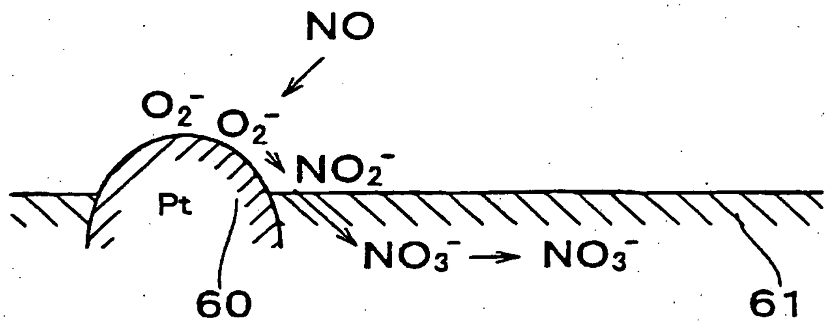


FIG. 8B

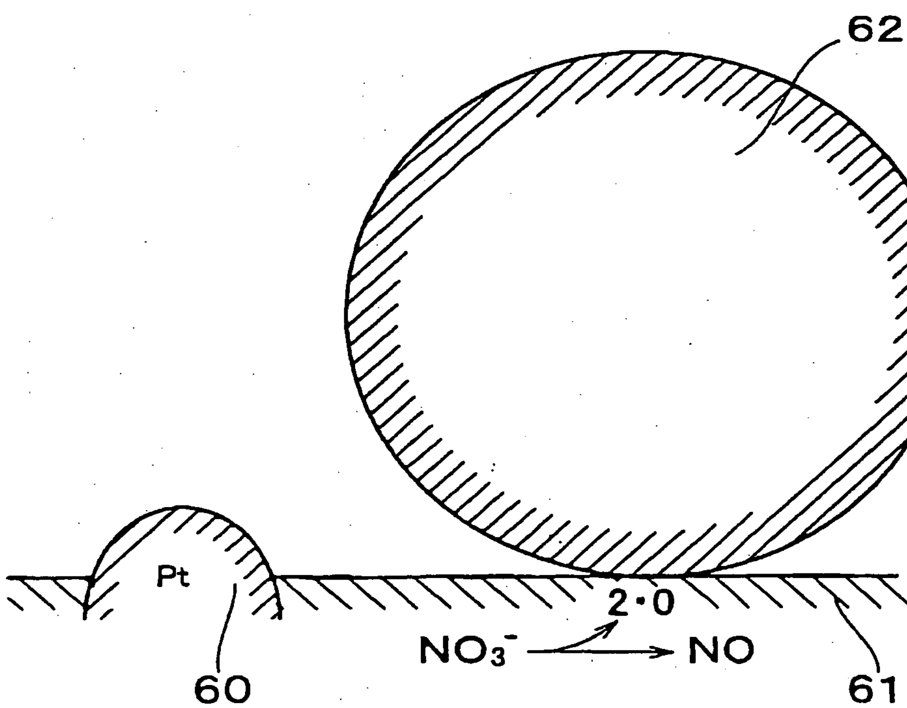


FIG. 9A

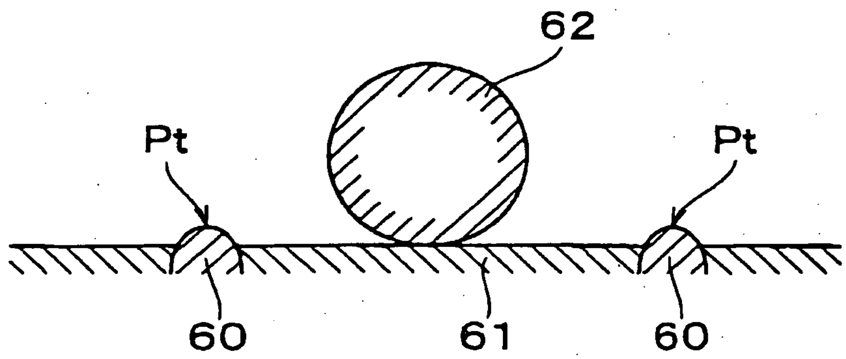


FIG. 9B

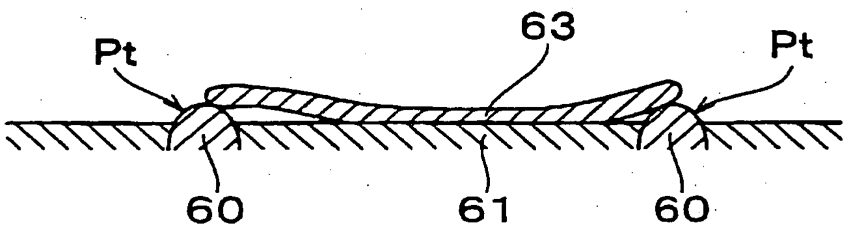
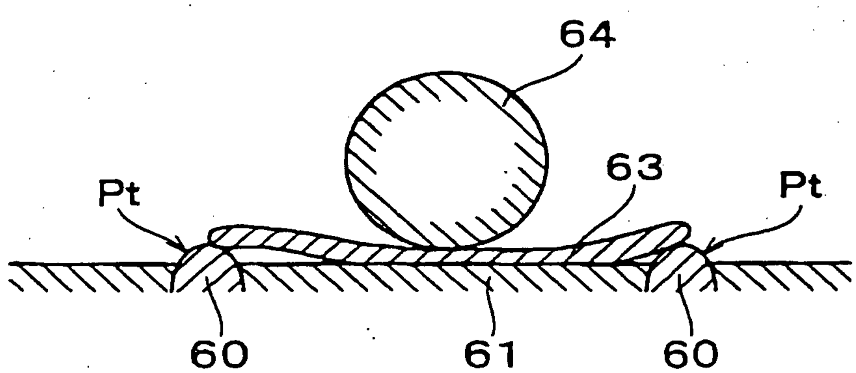
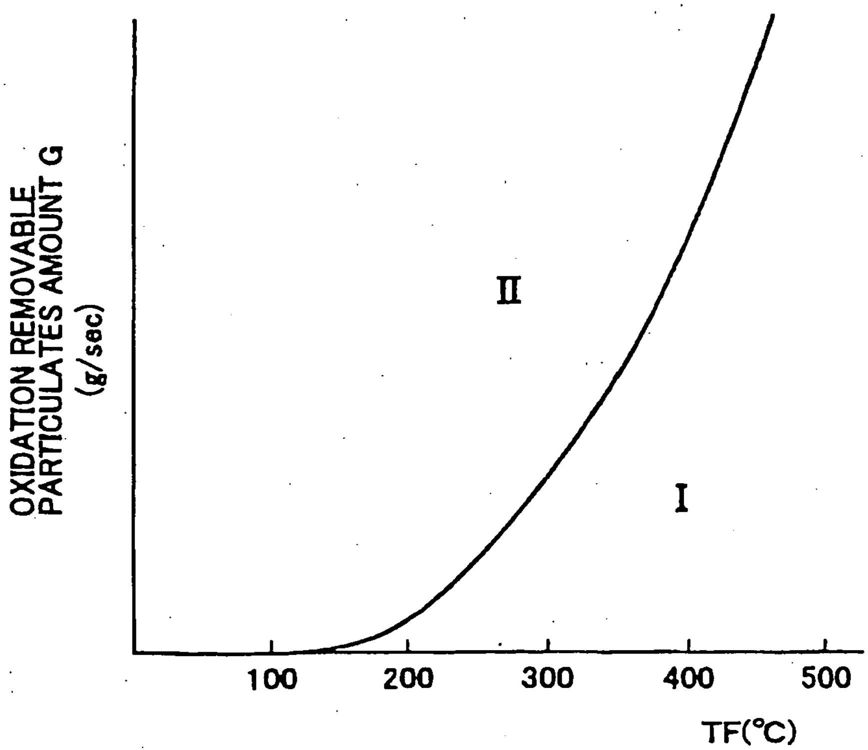


FIG. 9C



F I G. 10


OXIDATION REMOVABLE PARTICULATES AMOUNT G (g/sec)
II
I
100
200
300
400
500
TF(°C)

INTERNATIONAL SEARCH REPORT

Inte al Application No
PCT/IB 02/03114

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 F01N3/28 B28B3/20

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 F01N B28B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	EP 0 042 302 A (NGK INSULATORS LTD) 23 December 1981 (1981-12-23) page 2, line 1 -page 3, line 20; figures 3-5	1,13 2,3,6-9, 14
Y	DE 199 22 357 C (SWARS HELMUT) 9 November 2000 (2000-11-09) column 8, line 11 -column 14, line 58; figures 6,25	2,14
Y	US 5 468 455 A (BRUECK ROLF) 21 November 1995 (1995-11-21) column 6, line 60 -column 8, line 24; figures 1,6	3,6-9
A	DE 195 47 599 A (DEGUSSA) 26 June 1997 (1997-06-26) column 2, line 18 -column 4, line 55	4,12,17

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
4 November 2002	08/11/2002

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Nobre, S

INTERNATIONAL SEARCH REPORT

Inte al Application No
PCT/IB 02/03114

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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NAKATANI ET AL
10/333,414
1/21/2003
114730

DESCRIPTION

AN EXHAUST GAS PURIFICATION DEVICE

Technical Field

The invention relates to an exhaust gas purification device.

Background Art

A particulate filter for collecting particulates contained in exhaust gas discharged from an engine is known. The filter has a honeycomb structure formed of porous material. Further, the filter has a plurality of passages, some of them being closed at their upstream end by plugs, and remaining of them being closed at their downstream end by plugs. In this filter, the exhaust gas passes through partitions defining the passages, and thereafter flows out of the filter.

In this type of the filter, as the exhaust gas flows out of the filter after passing through the partitions, the filter has a high particulate collection ratio. However, the passages of the filter are closed by the plugs, and therefore, the productivity of the filter is low and the cost for producing the filter is high.

Further, as shown in Fig. 3A, as the exhaust gas hits against the plugs, the exhaust gas does not flow smoothly into the passages of the filter. In addition, when the exhaust gas flows near the upstream plugs, the exhaust gas flows with turbulence, and thus the exhaust gas does not flow smoothly into the passages of the filter. Further, as shown in Fig. 3B, when the exhaust gas flows near the downstream plugs, the exhaust gas flows with turbulence, and thus the exhaust gas does not flow smoothly out of the filter. For these reasons, the filter has a large pressure loss.

The purpose of the invention is to provide an exhaust gas purification device having a particulate

filter having a small pressure loss.

Disclosure of Invention

In the first invention, there is provided an exhaust gas purification device comprising a substrate used for purifying components contained in an exhaust gas discharged from an engine, the substrate having partitions which define passages and are formed of porous material having fine pores each having a predetermined average size, the end portions of the adjacent partitions defining each of part of the passages of the substrate being partially connected to each other such that the end portions are tapered toward the outside of the substrate, the tapered end portions partially closing the end opening of the corresponding passage and forming a small hole defined by the tips thereof, and the size of each small hole being smaller than the cross sectional area of the corresponding passage and larger than the sizes of the fine pores of the partitions.

In the second invention, according to the first invention, the end portions of the adjacent partitions defining each of part of the passages of the substrate are partially connected to each other at their upstream ends such that the end portions are tapered toward the outside of the substrate, and the end portions of the adjacent partitions defining each of remaining passages of the substrate are partially connected to each other at their downstream ends such that the end portions are tapered toward the outside of the substrate.

In the third invention, according to the second invention, the tapered end portions and the remaining partitions carry oxidation material for oxidizing the particulates, and the amount of the oxidation material carried by each upstream tapered end portion per unit volume is larger than that carried by each downstream tapered end portion per unit volume.

In the fourth invention, according to the first

invention, the end portions of the adjacent partitions defining each of part of the passages of the substrate are partially connected to each other at their upstream ends such that the end portions are tapered toward the outside of the substrate, and the end portions of the adjacent partitions defining each of remaining passages of the substrate are connected to each other at their downstream ends such that the end portions are tapered toward the outside of the substrate and the downstream end opening of the passage is completely closed.

In the fifth invention, according to the first invention, the end portions of the adjacent partitions defining each of part of the passages of the substrate are partially connected to each other at their downstream ends such that the end portions are tapered toward the outside of the substrate, and the end portions of the adjacent partitions defining each of remaining passages of the substrate are connected to each other at their upstream ends such that the end portions are tapered toward the outside of the substrate and the upstream end opening of the passage is completely closed.

In the sixth invention, according to the first invention, the substrate is used as a particulate filter arranged in an exhaust gas passage of an engine for collecting particulates contained in an exhaust gas discharged from an engine.

In the seventh invention, according to the sixth invention, the tapered end portions carry oxidation material for oxidizing the particulates.

In the eighth invention, according to the seventh invention, the amount of the oxidation material carried by each tapered end portion at its upstream surface per unit are is larger than that at its downstream surface per unit area.

In the ninth invention, according to the seventh invention, a process for increasing the temperature of the filter is performed.

In the tenth invention, according to the seventh invention, the filter carries a NOx carrying agent to take in and carry the NOx therein when excessive oxygen exists therearound, and to discharge the carried NOx therefrom when the concentration of the oxygen decreases.

In the eleventh invention, according to the seventh invention, the filter carries a precious metal catalyst.

In the twelfth invention, according to the eleventh invention, the oxidation material is an active oxygen production agent to take in and carry the oxygen when excessive oxygen exists therearound, and to discharge the carried oxygen therefrom in the form of active oxygen when the concentration of the oxygen decreases, and the active oxygen production agent discharges the active oxygen therefrom when the particulates adhere to the filter to oxidize the particulate adhering to the filter by the active oxygen.

In the thirteenth invention, according to the twelfth invention, the active oxygen production agent comprises one of an alkali metal, an alkali earth metal, a rare earth and a transition metal.

In the fourteenth invention, according to the twelfth invention, the active oxygen production agent comprises one of an alkali metal and an alkali earth metal having an ionization tendency higher than that of calcium.

In the fifteenth invention, according to the twelfth invention, the air fuel ratio of at least part of the exhaust gas flowing into the filter is temporarily made rich to oxidize the particulates adhering to the filter.

In the sixteenth invention, according to the sixth invention, an oxidation means for oxidizing components contained in the exhaust gas is arranged in the exhaust gas passage of the engine upstream of the filter.

In the seventeenth invention, according to the sixteenth invention, the oxidation means is an oxidation catalyst.

In the eighteenth invention, according to the sixteenth invention, the oxidation means is a NOx catalyst to carry the NOx when the lean exhaust gas flows thereinto and to reduce the carried NOx when the rich exhaust gas flows thereinto.

In the nineteenth invention, according to the sixth invention, the size of each small hole of the filter at the low temperature region of the filter is larger than that at the high temperature region of the filter.

In the twentieth invention, according to the nineteenth invention, the low temperature region is the peripheral region of the filter, and the high temperature region is the central region of the filter.

In the twenty-first invention, according to the nineteenth invention, the cross sectional area of each passage of the filter at the low temperature region of the filter is larger than that at the high temperature region of the filter.

In the twenty-second invention, according to the sixth invention, the cross sectional area of each passage of the filter at the low temperature region of the filter is larger than that at the high temperature region of the filter.

In the twenty-third invention, according to the twenty-second invention, the low temperature region is the peripheral region of the filter, and the high temperature region is the central region of the filter.

In the twenty-fourth invention, according to the twenty-second invention, the size of each small hole of the filter at the low temperature region of the filter is larger than that at the high temperature region of the filter.

In the twenty-fifth invention, according to the sixth invention, an exhaust gas purification means for purifying components contained in the exhaust gas is arranged in the exhaust gas passage of the engine downstream of the filter.

In the twenty-sixth invention, according to the twenty-fifth invention, the exhaust gas purification means is a NOx catalyst to carry the NOx when the lean exhaust gas flows thereinto, and to reduce the carried NOx when at least the generally stoichiometric exhaust gas flows thereinto.

In the twenty-seventh invention, according to the twenty-fifth invention, the exhaust gas purification means is an additional particulate filter which can oxidize the particulates contained in the exhaust gas.

In the twenty-eighth invention, according to the twenty-fifth invention, the filter is arranged at least near the exhaust manifold.

In the twenty-ninth invention, according to the twenty-fifth invention, the device further comprises a bypass passage which extends from the engine exhaust gas passage between the filter and the exhaust gas purification means to the exhaust gas passage of the engine downstream of the exhaust gas purification means to bypass the exhaust gas purification means, and a switch valve for switching the flow of the exhaust gas into the exhaust gas purification means and into the bypass passage, the filter carries a SOx carrying agent to carry the SOx when the lean exhaust gas flows thereinto, and to release the carried SOx when at least the generally stoichiometric exhaust gas flows thereinto and the temperature of the SOx carrying agent has a temperature higher than a SOx release temperature, the switch valve is positioned such that the exhaust gas flows into the exhaust gas purification means when the SOx is not released from the SOx carrying agent, and is positioned such that the exhaust gas flows into the bypass passage when the SOx is released from the SOx carrying agent.

In the thirtieth invention, according to the twenty ninth invention, a catalyst for oxidizing the components contained in the exhaust gas is arranged in the bypass

passage.

In the thirty-first invention, according to the first invention, the substrate is arranged in an exhaust gas passage of an engine, the substrate carrying a hydrocarbon collection agent for collecting unburned hydrocarbon contained in an exhaust gas discharged from an engine, and a hydrocarbon purification catalyst for purifying unburned hydrocarbon, the hydrocarbon collection agent collects unburned hydrocarbon when the agent has a temperature lower than a hydrocarbon release temperature, and releases the collected unburned hydrocarbon therefrom when the agent has a temperature higher than the hydrocarbon release temperature, the hydrocarbon purification catalyst purifies unburned hydrocarbon when the catalyst has a temperature higher than a hydrocarbon purification temperature, the hydrocarbon release temperature is set such that the unburned hydrocarbon is released from the hydrocarbon collection agent when the hydrocarbon purification catalyst has a temperature lower than the hydrocarbon purification temperature.

In the thirty-second invention, there is provided a method for producing a substrate used for purifying components contained in an exhaust gas discharged from an engine, the substrate having a plurality of exhaust gas passages defined by partitions formed of porous material, the end portions of the partitions defining each of part of the exhaust gas passages being partially connected to each other at one end of the exhaust gas passage such that the end portions are tapered toward the outside of the substrate and define a small hole by the tips thereof, the end portions of the partitions defining each of the remaining exhaust gas passages being partially connected to each other at the other end of the exhaust gas passage such that the end portions are tapered toward the outside of the substrate and define a small hole by the tips thereof, wherein the method comprises a step of

gathering and connecting the end portions of the partitions defining each exhaust gas passage to be closed at its end opening, and a step of forming a small hole defined by the tips of the end portions defining each exhaust gas passage to be closed at its end opening, each small hole having a size smaller than the area of the end opening of the corresponding exhaust gas passage and larger than the average sizes of the fine pores of the partitions.

In the thirty-third invention, according to the thirty-second invention, the gathering and connecting step and the small hole forming step are simultaneously performed.

In the thirty-fourth invention, according to the thirty-third invention, the gathering and connecting step and the small hole forming step are simultaneously performed by pressing a device having a plurality of projections and pins arranged between the projections onto the end face of the substrate.

In the thirty-fifth invention, according to the thirty-second invention, first, the gathering and connecting step is performed, and then the small hole forming step is performed.

In the thirty-sixth invention, according to the thirty-fifth invention, in the small hole forming step, the tips of the end portions connected to each other are shaved to form the small hole.

Brief Description of Drawings

Figs. 1A and 1B show a particulate filter of the invention;

Figs. 2A and 2B show a part of the filter of the invention;

Figs. 3A and 3B show a part of the filter of the prior art;

Figs. 4A and 4B show a honeycomb structure;

Figs. 5A and 5B show a die;

Figs. 6A and 6B show an action of the oxidization of the particulates;

Figs. 7A, 7B and 7C show an action of deposition of the particulates;

Figs. 8 shows a relationship between the amount of the particulates purified by the oxidation and the temperature of the filter;

Fig. 9 shows the filter of the second embodiment;

Fig. 10 shows the filter of the third embodiment;

Fig. 11 shows an engine provided with the filter of the invention;

Fig. 12 shows a flowchart for controlling the engine operation;

Fig. 13 shows the engine provided with the exhaust gas purification device of the fourth embodiment;

Fig. 14 shows an oxidization catalyst of the fourth embodiment;

Fig. 15 shows the filter of the fifth embodiment;

Fig. 16 shows the filter of the sixth embodiment;

Fig. 17 shows the engine provided with the exhaust gas purification device of the seventh embodiment;

Fig. 18 shows a main particulate filter of the seventh embodiment;

Fig. 19 shows an action of the oxidation of the particulates by the main filter;

Fig. 20 shows the engine provided with the exhaust gas purification device of the modified seventh embodiment;

Fig. 21 shows the engine provided with the exhaust gas purification device of the eighth embodiment;

Fig. 22A shows ratios of the discharged NOx and SOx;

Fig. 22B shows total amounts of the discharged NOx and SOx;

Fig. 23 shows the exhaust gas purification device of the ninth embodiment;

Fig. 24 shows the filter produced by the second

filter production method;

Fig. 25 shows a closure device used in the second filter production method;

Fig. 26 shows the second filter production method;

Fig. 27 shows the closure device used in the third filter production method;

Fig. 28 shows the closure device used in the third filter production method;

Fig. 29 shows the third filter production method;

Fig. 30 shows the closure device used in the fourth filter production method;

Fig. 31 shows the closure device used in the fifth filter production method;

Fig. 32 shows the details of the closure device shown in Fig. 31;

Fig. 33 shows the closure device used in the sixth filter production device; and

Fig. 34 shows the seventh filter production method.

Best Mode for Carrying Out the Invention

The invention will be explained by referring to the drawings. Figs. 1A and 1B show an end view and a longitudinal cross sectional view of the filter, respectively. As shown in Figs. 1A and 1B, the filter 22 has a honeycomb structure, and a plurality of exhaust gas passages 50,51 extending parallel to each other.

The exhaust gas passages of the filter 22 comprise exhaust gas inflow passages 50. At the downstream end region, each inflow passage 50 has a cross sectional area which is made smaller than that of its remaining region by a corresponding tapered wall portion 52. Further, the exhaust gas passages of the filter 22 comprise exhaust gas outflow passages 51. At the upstream end region, each outflow passage 51 has a cross sectional area which is made larger than that of its remaining region by a corresponding tapered wall portion 53.

Each downstream tapered wall portion 52 is formed by

gathering and connecting the downstream end portions of partitions 54 defining the corresponding exhaust gas inflow passage 50 to each other. On the other hand, each upstream tapered wall portion 53 is formed by gathering and connecting the upstream end portions of partitions 54 defining the corresponding exhaust gas outflow passage 51 to each other.

Each inflow passage 50 has a small hole 55 at the tip of the corresponding downstream tapered wall portion 52. Each small hole 55 has a cross sectional area smaller than that of the corresponding inflow passage 50. On the other hand, each outflow passage 51 has a small hole 56 at the tip of the corresponding upstream tapered wall portion 53. Each small hole 56 has a cross sectional area smaller than that of the corresponding outflow passage 51. In other words, the downstream end openings of some of the exhaust gas passages 50 are partially closed by the downstream tapered wall portions 52 to define the small holes 55 therein. On the other hand, the upstream end openings of remaining exhaust gas passages 51 are partially closed by the upstream tapered wall portions 53 to define the small holes 56 therein.

According to the present invention, the exhaust gas passages 50,51 of the filter 22 are alternatively positioned and the thin partitions 54 are positioned between the passages 50,51. In other words, the inflow passage 50 is enclosed by four outflow passages 51, and the outflow passage 51 is enclosed by four inflow passages 50. Therefore, the cross sectional area of one of two adjacent exhaust gas passages of the filter 22 is decreased at its downstream end region by the corresponding downstream tapered wall portion 52, and the cross sectional area of the other exhaust gas passage is decreased at its upstream end region by the corresponding upstream tapered wall portion 53.

The filter 22 is formed of porous material such as cordierite. Cordierite has fine pores each having a

predetermined average size. Therefore, as shown by an arrow in Fig. 1B, the exhaust gas flowing into the inflow passages 50 flows into the adjacent outflow passages 51 through the fine pores of the surrounding partitions 54. As the tapered wall portions 52,53 are also formed of the same material as the partitions 54, the exhaust gas flows into the outflow passages 51 through the fine pores of the upstream tapered wall portions 53 as shown in Fig. 2A and flows out of the inflow passages 50 through the fin pores of the downstream tapered wall portions 52 as shown in Fig. 2B.

Further, the exhaust gas flows into the outflow passages 51 through the upstream small holes 56, and flows out of the inflow passages 50 through the downstream small holes 55.

Each hole 55,56 has a size larger than the average sizes of the fine pores of the tapered wall portions 52,53. Further, the downstream small holes 55 have generally the same sizes as each other, and the upstream small holes 56 have generally the same sizes as each other. Furthermore, the downstream small holes 55 may have generally the same as or, different sizes from those of the upstream small holes 56.

If the small holes 55,56 have large sizes, the filter 22 has a small pressure loss and a low particulate collection ratio. Contrary to this, if the small holes 55,56 have small sizes, the filter 22 has a large pressure loss and a high particulate collection ratio. According to the present invention, the size of the hole 55,56 is determined such that the pressure loss and the particulate collection ratio of the filter 22 are suitably balanced. Further, according to the present invention, the size of the hole 55,56 is determined such that the amount of the particulates flowing out of the filter 22 is kept smaller than an allowed amount. The amount of the particulates flowing out of the filter 22 can be calculated on the basis of the amount of the

particulates flowing into the filter 22 per unit time and the particulate collection ratio of the filter 22.

In the present invention, the particulate collection ratio and the pressure loss of the filter 22 can be easily changed by changing the size of the holes 55,56 in accordance with the target particulate collection ratio of the filter 22.

Each upstream tapered wall portion 53 conically converges toward its upstream end such that the cross sectional area of the corresponding outflow passage 51 decreases continuously. Therefore, the upstream end of each inflow passage 50 defined by the corresponding upstream tapered wall portion 53 conically diverges toward its upstream end such that the cross sectional area of the corresponding inflow passage 50 increases continuously. According to this structure, the exhaust gas smoothly flows into the filter 22 contrary to the case that the entrances of the inflow passages are constituted as shown in Fig. 3A.

In the filter as shown in Fig. 3A, each inflow passage is closed at its upstream end by a plug 72. In this case, as shown by the reference number 73, the exhaust gas hits against the plugs 72, and the filter has a large pressure loss. In addition, as shown by the reference number 74, when the exhaust gas flows near the plugs 72, the exhaust gas flows with turbulence around the entrances of the inflow passages, and thus the exhaust gas does not smoothly flow into the inflow passages. Thus, the filter has a large pressure loss.

On the other hand, in the filter 22 of the invention, as shown in Fig. 2A, the exhaust gas flows into the inflow passages 50 without turbulence. Therefore, according to the present invention, the exhaust gas smoothly flows into the filter 22, and thus the filter 22 has a small pressure loss.

In the filter shown in Figs. 3A and 3B, as the exhaust gas hits against the plugs 72 and flows with

turbulence around the plugs 72, the particulates easily deposit on the upstream end surfaces of the plugs 72 and the wall surfaces of the partitions adjacent thereto. However, in the filter 22 of the present invention, as each upstream tapered wall portions 53 has a conical shape, the tapered wall portion 53 has no upstream end surface which the exhaust gas hit against, and the exhaust gas does not flow with turbulence around the upstream end surface of the tapered wall portion 53. Therefore, according to the present invention, many particulates hardly deposit in the filter 22 at its upstream region, and the pressure loss of the filter 22 hardly increases.

On the other hand, each downstream tapered wall portion 52 conically converges toward its downstream end such that the cross sectional area of the corresponding inflow passage 50 decreases continuously. Therefore, the downstream end of each outflow passage 51 defined by the corresponding downstream tapered wall portion 52 conically diverges toward its downstream end such that the cross sectional area of the corresponding outflow passage 51 increases continuously. According to this structure, the exhaust gas smoothly flows out of the filter 22 contrary to the case that the exits of the outflow passages are constituted as shown in Fig. 3A.

In the filter shown in Fig. 3B, each outflow passage is closed at its downstream end by a plug 70, and extends straight to its exit. Therefore, turbulence 71 occurs around the exits of the outflow passages. In this case, the exhaust gas does not smoothly flow out of the outflow passages.

On the other hand, in the filter 22 of the invention, as shown in Fig. 2B, the exhaust gas flows out of the exit of the outflow passages 51 without turbulence. Therefore, according to the present invention, the exhaust gas smoothly flows out of the filter 22, and thus the filter 22 has a small pressure

loss.

As long as each tapered wall portion continuously converges toward the outside of the filter 22, the tapered wall portion may be in the form other than the conical form, such as a quadrangular pyramid or a six sided pyramid.

It is preferred that the filter has potentially a small pressure loss. Further, an engine operation control is designed in consideration of the potential pressure loss of the filter. Therefore, if the pressure loss of the filter increases from the potential pressure loss during the engine operation, the performance of the engine decreases. Regarding the filter, it is important that the filter has a small potential pressure loss and the pressure loss of the filter is kept around the potential pressure loss even if the pressure loss of the filter increases in use of the filter.

According to the present invention, as the partitions 54 defining the upstream end region of the exhaust gas passages 50,51 of the filter 22 are tapered, the exhaust gas hardly flows with turbulence when the exhaust gas flows into the exhaust gas passages 50,51, and thus the pressure loss of the filter 22 is potentially small.

Further, according to the present invention, since the partitions 54 defining the upstream end regions of the exhaust gas passages 50,51 of the filter 22 are tapered, the particulates hardly deposit on the surfaces of the tapered wall portions 52,53. In other words, in use of the filter 22, the particulates hardly deposit on the surfaces of the tapered wall portions 52,53, and thus the exhaust gas flowing into the exhaust gas passages hardly flows with turbulence by the deposited particulates. Therefore, even if the pressure loss of the filter increases in use thereof, the pressure loss of the filter hardly increases to a value considerably larger than the potential pressure loss.

Other than the particulates, the exhaust gas contains incombustible inorganic residuals (ash) produced by the burning of the fuel. Therefore, the ash flows into the filter 22, and deposits therein.

When the amount of the ash depositing in the inflow passages 50 increases, the pressure loss of the filter 22 increases. As explained above, in use of the filter 22, it is important that the pressure loss of the filter 22 is kept around the potential pressure loss even if the pressure loss of the filter 22 increases. To this end, the amount of the depositing ash must be small. Further, it is preferred that the ash depositing in the inflow passages 50 is removed.

According to the present invention, the small holes 55 are formed in the downstream tapered wall portions 52, and thus the ash flowing into the inflow passages 50 can flow out through the downstream small holes 55. Therefore, the ash hardly deposits in the inflow passages 50, and thus the pressure loss of the filter 22 hardly increases to a value considerably larger than the potential pressure loss even if the pressure loss of the filter 22 increases.

Further, when the amount of the ash depositing in the inflow passages 50 increases, the quantity of the exhaust gas passing through the small holes 55,56 increases. Therefore, the amount of the ash newly depositing in the inflow passages 50 decreases, and thus the pressure loss of the filter 22 hardly increases to a value considerably larger than the potential pressure loss even if the pressure loss of the filter 22 increases.

Further, when the amounts of the ash and the particulates depositing in each inflow passage 50 increase, and then the pressure in the inflow passage 50 increases, the increased pressure moves the ash depositing in the inflow passage 50 toward its downstream region, and finally discharges the ash through the

corresponding downstream small hole 55. Therefor , the pressure loss of the filter 22 hardly increases to a value considerably larger than the potential pressure loss even if the pressure loss of the filter 22 increases. In addition, as the ash depositing in the inflow passages 50 is discharged from the filter 22 by the pressure in the inflow passages 50, the number of the operations to discharge the ash from the filter 22 is reduced.

Further, when the amounts of the ash and the particulates depositing in the inflow passages 50 increase, the exhaust gas does not easily pass through the partitions 54, and thus the pressures in the inflow passages 50 increase. At this time, the quantity of the exhaust gas passing through the small holes 55,56 increases. Therefore, the pressure loss of the filter 22 hardly increases to a value considerably larger than the potential pressure loss even if the pressure loss of the filter 22 increases.

Further, when many particulates deposit in the filter 22, and burn at once, the filter 22 may be melted by the heat derived from the burning of the particulates. However, according to the present invention, many particulates hardly deposit in the filter 22. Therefore, the filter is hardly melted by the heat derived from the burning of the particulates.

The invention may be applied to an exhaust gas purification filter arranged in the exhaust passage of the engine for collecting specific components contained in the exhaust gas, or to an exhaust gas purification catalyst arranged in the exhaust passage of the engine for purifying specific components contained in the exhaust gas.

A first method for producing a filter of the present invention will be explained. First, a cylindrical honeycomb structure 80 shown in Fig. 4 is extruded from porous material such as cordierite. Next, a die 90 shown

in Fig. 5 is pressed onto one of the end faces of the structure 80.

As shown in Fig. 5A, the die 90 has a plurality of conical projections 91. Fig. 5B shows one of the projections 91. The die 90 is pressed onto one end face of the structure 80 such that each projection 91 is inserted into a corresponding exhaust gas passage 50. As a result, four end portions of four adjacent partitions defining each exhaust gas passage 51 are gathered toward each other, and then are partially connected to each other to form a tapered wall portion 53 and a small hole 56.

Regarding the other end face of the structure 80, the similar processes are performed.

Next, the structure 80 is dried. Next, the structure 80 is baked. As a result, the filter 22 of the present invention is obtained. In this way, according to the present invention, the ends of the passages 50,51 are narrowed by a very simple method comprising the step of pressing the die 90 onto the end faces of the structure 80.

The step of pressing the die 90 onto the end faces of the structure 80 may be performed after the structure 80 is dried. Otherwise, after the baked structure 80 is softened at its end regions, the die 90 may be pressed onto the softened end portions of the structure 80. In this case, thereafter, the end portions of the structure 80 are baked again.

In the present invention, in use of the filter 22, the particulates do not easily deposit on the upstream tapered wall portions 53. However, in some cases, the particulates may deposit on the wall portions 53. In this case, in use of the filter 22, the pressure loss of the filter 22 increases. As explained above, in use of the filter 22, it is important to prevent the pressure loss of the filter from increasing to a value considerably larger than the potential pressure loss. To

this end, it is necessary to remove the particulates from the filter 22.

According to the present invention, an oxidation material for removing the particulates by oxidation is applied on the upstream tapered wall portions 53. According to this, the particulates collected by the tapered wall portions 53 are continuously removed by oxidation and many particulates hardly deposit on the upstream tapered wall portions 53. Therefore, in use of the filter 22, the pressure loss of the filter 22 hardly increases to a value considerably larger than the potential pressure loss even if the pressure loss of the filter 22 increases in use of the filter 22.

In this way, according to the present invention, a problem is solved, which specially derives from the structure of the porous tapered wall portions of the upstream ends of the outflow passages 51, that is, in which the pressure loss of the filter increases to a value considerably larger than the potential pressure loss during use of the filter.

In the present invention, the oxidation material is applied to the entire of the filter 22, that is, the partitions 54 and the downstream tapered wall portions 52 other than the upstream tapered wall portions 53. Further, in the present invention, the oxidation material is applied to the interior wall surfaces defining the fine pores of the upstream and downstream tapered wall portions 53,52 and the partitions 54 other than the exterior wall surfaces thereof. Furthermore, in the present invention, the amount of the oxidation material applied to the upstream tapered wall portions 53 per unit volume is larger than those applied to the partition 54 or the downstream tapered wall portions 52.

The exhaust gas more easily passes through the tapered wall portions 52,53 than the partitions 54. That is, the quantity of the exhaust gas passing through the tapered wall portions 52,53 per unit surface area is

larger than that passing through the partitions 54 per unit surface area. Therefore, commonly, the amount of the particulates depositing on the tapered wall portions 52,53 is larger than that depositing on the partitions 54, and thus the tapered wall portions 52,53 are more easily closed by the particulates than the partitions 54.

Opposed to this, according to the present invention, the amount of the oxidation material applied to the tapered wall portion 52,53 per unit volume is larger than that applied to the partition 54 per unit volume. According to this, the amount of the particulates removed by oxidation on each tapered wall portion 52,53 per unit time is larger than that on each partition 54 per unit time. Therefore, many particulates hardly deposit on the tapered wall portions 52,53.

The exhaust gas is difficult to pass through the tapered wall portions 52,53 if much oxidation material is applied to the tapered wall portions 52,53. Therefore, the exhaust gas generally uniformly passes through the tapered wall portions 52,53 and the partitions 54. Thus, many particulates hardly deposit on the tapered wall portions 52,53. Further, the tapered wall portions 52, 53 and the partitions 54 are efficiently used for collecting the particulates.

The amount of the particulates depositing on each tapered wall portion 52,53 at its upstream wall surface is larger than that at its downstream wall surface. That is, the tapered wall portions 52,53 are more easily closed at their upstream wall surfaces by the particulates than at their downstream wall surfaces. According to the present invention, the amount of the oxidation material applied to the upstream wall surface of each tapered wall portion 52,53 per unit volume is larger than that applied to the downstream wall surface thereof. According to this, the fine pores of the tapered wall portions 52,53 are hardly closed by the particulates.

The oxidation material applied to the filter will be explained in detail. In the present invention, a carrier layer is formed of the material such as alumina on the surrounding wall surfaces of the exhaust gas passages 50,51, i.e., the entire of the both sides of the partitions 54 and the tapered wall portions 52,53. Precious metal catalyst and active oxygen production agent are carried on the carrier layer. The agent takes and carries the oxygen when the excess of the oxygen exists around the agent, and discharges the carried oxygen therefrom in the form of an active oxygen when the concentration of the oxygen around the agent decreases. In the first embodiment, the oxidation material is constituted by the active oxygen production agent.

In the first embodiment, a platinum (Pt) is used as the precious metal catalyst, and at least one of the material selected from an alkali metal such as potassium (K), sodium (Na), lithium (Li), cesium (Cs) or rubidium (Rb), an alkali earth metal such as barium (Ba), calcium (Ca) or strontium (Sr), or a rare earth such as lanthanum (La), yttrium (Y) or Cerium (Ce), a transition metal such as iron (Fe), or a carbon family element such as Tin (Sn), is used as the active oxygen production agent.

It is preferred that an alkali metal or an alkali earth metal having an ionization tendency larger than calcium, that is, potassium, lithium, cesium, rubidium, barium or strontium is used as the active oxygen production agent.

The action of removal of the particulates by the filter will be explained in the case that platinum and potassium are carried on the carrier layer. Note that the action of removal of the particulates by the filter carrying other precious metal and other alkali metal, or alkali earth metal, or rare earth, or transition metal is generally the same as that explained below.

For example, in the case that the engine is a type of the compression ignition engine in which the fuel

burns under an excess of the oxygen in the combustion chamber, the exhaust gas flowing into the filter 22 contains excessive oxygen. That is, in the case that the air fuel ratio of the mixture in the combustion chamber 5 is referred to as the air fuel ratio of the exhaust gas, in the compression ignition engine, the air fuel ratio of the exhaust gas is lean. Further, nitrogen monoxide (NO) is produced in the combustion chamber 5 of the compression ignition engine, and thus the exhaust gas contains NO. Furthermore, the fuel contains a sulfur constituent (S). The sulfur constituent reacts with the oxygen in the combustion chamber 5 and becomes sulfur dioxide (SO_2). Therefore, the exhaust gas contains SO_2. Thus, the exhaust gas containing the excessive oxygen, NO, and SO_2 flows into the inflow passages 50 of the filter 22.

As explained above, the exhaust gas contains the excessive oxygen and, thus, if the exhaust gas flows into the inflow passages 50 of the filter 22, as shown in Fig. 6A, the oxygen (O_2) adheres to the surface of the platinum in the form of O_2^- or O^{2-}. On the other hand, the NO in the exhaust gas reacts with the O_2^- or O^{2-} on the surface of the platinum to become NO_2 ($2NO+O_2 \rightarrow 2NO_2$). Next, part of the produced NO_2 is oxidized on the platinum and is adsorbed to the active oxygen production agent 61, and thus is carried in the agent 61 in the form of nitrate ions NO_3^-. Otherwise, part of the produced NO_2 is oxidized on the platinum and is absorbed and diffuses in the agent 61, and thus is carried in the agent 61 in the form of nitrate ions (NO_3^-). As shown in Fig. 6A, the nitrate ions NO_3^- bond with potassium to produce potassium nitrate (KNO_3).

On the other hand, as explained above, the exhaust gas also contains SO_2. This SO_2 is carried in the active oxygen production agent 61 by a mechanism similar to that of NO. That is, the oxygen (O_2) adheres to the surface of the platinum in the form of O_2^- or O^{2-}. The SO_2 in the

exhaust gas reacts with the O_2^- or O^{2-} on the surface of the platinum to become SO_3. Next, part of the produced SO_3 is oxidized on the platinum and is adsorbed to the agent 61, and thus is carried in the agent 61 in the form of sulfate ions (SO_4^{2-}). Otherwise, part of the produced SO_3 is oxidized on the platinum and is absorbed and diffuses in the agent 61, and thus is held in the agent 61 in the form of sulfate ions (SO_4^{2-}). The sulfate ions (SO_4^{2-}) bond with the potassium to produce potassium sulfate (K_2SO_4).

On the other hand, particulates comprised of mainly carbon (C), that is, soot, are produced in the combustion chamber 5. Therefore, the exhaust gas contains particulates. The particulates contact and adhere to the surface of the carrier layer, for example, the surface of the active oxygen production agent 61 as shown in Fig. 6B when the exhaust gas flows in the inflow passages 50 of the filter 22 or passes through the partitions 54.

If the particulates 62 adhere to the surface of the active oxygen production agent 61 in this way, the concentration of oxygen at the contact surface between the particulate 62 and the agent 61 falls. If the concentration of oxygen falls, a difference in concentration occurs with the inside of the high oxygen concentration active oxygen production agent 61, and therefore the oxygen in the agent 61 moves toward the contact surface between the particulate 62 and the agent 61. As a result, the potassium nitrate (KNO_3) formed in the agent 61 is broken down into potassium, oxygen, and NO. The oxygen moves toward the contact surface between the particulate 62 and the agent 61, while the NO is released from the surface or the inside of the agent 61 to the outside. The NO released to the outside is oxidized on the downstream side platinum and is again carried by adsorption or absorption in the agent 61.

On the other hand, at this time, the potassium sulfate (K_2SO_4) formed in the active oxygen production

agent 61 is also broken down into potassium, oxygen, and SO_2. The oxygen moves toward the contact surface between the particulate 62 and the agent 61, while the SO_2 is released from the surface or the inside of the agent 61 to the outside. The SO_2 released to the outside is oxidized on the downstream side platinum and again carried by adsorption or absorption in the agent 61. Note that, since the potassium sulfate is stable and does not easily dissolve, the potassium sulfate does not easily release the active oxygen compared with the potassium nitrate.

As explained above, the active oxygen production agent 61 produces and releases the active oxygen by the reaction with the oxygen when the agent 61 absorbs the NOx therein in the form of the nitrate ions (NO_3^-). Similarly, as explained above, the agent 61 produces and releases the active oxygen by the reaction with the oxygen when the agent 61 absorbs the SO_2 therein in the form of the sulfate ions (SO_4^{2-}).

The oxygen moving toward the contact surface between the particulate 62 and the active oxygen production agent 61 is the oxygen broken down from compounds such as potassium nitrate (KNO_3) or potassium sulfate (K_2SO_4). The oxygen broken down from these compounds has an unpaired electron and thus is the active oxygen having an extremely high reactivity. Therefore, the oxygen moving toward the contact surface between the particulate 62 and the agent 61 becomes the active oxygen. Similarly, the oxygen produced by the reaction of the NOx and the oxygen in the agent 61 or the reaction of the SO_2 and the oxygen in the agent 61 becomes the active oxygen. If the active oxygen contacts the particulate 62, the particulate 62 is oxidized without emitting a luminous flame in a short period (from several seconds to several minutes) and the particulate 62 is completely removed. Therefore, the particulates hardly deposit on the filter 22.

In the prior art, when the particulates depositing

in layers on the filter burn, the filter becomes red hot and burns along with a flame. This burning along with a flame does not continue unless the temperature is high. Therefore, to continue the burning along with a flame, the temperature of the filter must be maintained high.

As opposed to this, in the present invention, the particulate 62 is oxidized without emitting a luminous flame as explained above. At this time, the surface of the filter 22 does not become red hot. That is, in the present invention, the particulate 62 is removed by oxidation at a low temperature compared to the prior art. Therefore, the action of removal of the particulate 62 by oxidation without emitting a luminous flame according to the present invention is completely different from the action of removal of particulate by burning along with a flame.

The higher the temperature of the filter 22, the more active the platinum and the active oxygen production agent 61 become. Therefore, the higher the temperature of the filter 22, the amount of the particulates removable by oxidation without emitting a luminous flame on the filter 22 per unit time increases.

The solid line in Fig. 8 shows the amount G of the particulates removable by oxidation without emitting a luminous flame per unit time. The abscissa of Fig. 8 shows the temperature TF of the filter 22. If the amount of particulates flowing into the filter per unit time is called the inflowing particulate amount M, in the state that the inflowing particulate amount M is smaller than the amount G of particulates removable by oxidation, that is, in the region I of Fig. 8, when the particulates contact the filter 22, all of the particulates flowing into the filter 22 are removed by oxidation successively in a short time (from several seconds to several minutes) without emitting a luminous flame on the filter 22.

As opposed to this, in the state that th inflowing particulate amount M is larger than the amount G of

particulates removable by oxidation, that is, in the region II of Fig. 21, the amount of the active oxygen is not sufficient for successive oxidation of all of the particulates. Figs. 7A to 7C show the state of oxidation of particulates in this case.

That is, in the state that the amount of active oxygen is not sufficient for successive oxidation of all of the particulates, if the particulate 62 adheres to the active oxygen production agent 61 as shown in Fig. 7A, only part of the particulate 62 is oxidized. The portion of the particulate not sufficiently oxidized remains on the carrier layer of the active oxygen particulate agent 61. Next, if the state of an insufficient amount of active oxygen continues, the portions of the particulates not oxidized successively remain on the carrier layer. As a result, as shown in Fig. 7B, the surface of the carrier layer is covered by the residual particulate portion 63.

When the surface of the carrier layer is covered by the residual particulate portion 63, the platinum does not easily oxidize the NO and SO_2, and the active oxygen production agent 61 does not easily release the active oxygen, and thus the residual particulate portion 63 is not oxidized and easily remains as it is. As a result, as shown in Fig. 7C, other particulates 64 successively deposit on the residual particulate portion 63. That is, the particulates deposit in layers.

If the particulates deposit in layers in this way, the particulates will not be oxidized by the active oxygen. Therefore, other particulates successively deposit on the particulate 64. That is, if the inflowing particulate amount M continues to be larger than the amount G of particulates removable by oxidation, the particulates deposit in layers on the filter 22 and therefore unless the temperature of the exhaust gas is made higher or the temperature of the filter 22 is made higher, it is no longer possible to cause the deposited

particulates to ignite and burn.

As explained above, in the region I of Fig. 8, the particulates are oxidized in a short time without emitting a luminous flame on the filter 22. In the region II of Fig. 8, the particulates deposit in layers in the filter 22. Therefore, to prevent the particulates from depositing in layers in the filter 22, the inflowing particulate amount M must be maintained smaller than the amount G of the particulates removable by oxidation at all times.

As can be understood from Fig. 8, in the filter 22 of the present invention, the particulates can be oxidized even if the temperature TF of the filter 22 is considerably low. Therefore, it is possible to maintain the inflowing particulate amount M and the filter temperature TF such that the inflowing particulate amount M is normally maintained smaller than the amount G of the particulates removable by oxidation. If the inflowing particulate amount M is maintained smaller than the amount G of the particulates removable by oxidation at all time, the particulates hardly deposit in the filter 22 and the pressure loss of the filter 22 hardly increases.

On the other hand, as explained above, in the state that the particulates deposit in layers on the filter 22, the active oxygen does not easily oxidize the particulates even when the inflowing particulate amount M becomes smaller than the amount G of the particulate removable by oxidation. However, when the portions of the particulates not oxidized begin to remain, that is, the amount of the depositing particulates is smaller than an allowed limit, if the inflowing particulate amount M becomes smaller than the amount G of the particulates removable by oxidation, the remaining portions of the particulates are oxidized and removed by the active oxygen without emitting a luminous flame.

The filter of the second embodiment will be

explained. Figs. 9A and 9B show the filter of the second embodiment. Figs. 9A and 9B show an end view and a longitudinal cross sectional view of the filter, respectively. The structure of the filter of the second embodiment is basically the same as that of the first embodiment.

In the second embodiment, similar to the first embodiment, a small hole 55 is formed in the tip of each downstream tapered wall portion 52. However, no small hole is formed in the tips of the upstream tapered wall portions 53. That is, the inflow passages 53 are completely closed by the upstream tapered wall portions 53. Therefore, the particulate collection ratio of the filter of the second embodiment is larger than that of the first embodiment.

In the second embodiment, even if the ash and the particulates deposit in the inflow passages 50, and then the exhaust gas does not easily pass through the partitions 54, the exhaust gas newly flowing into the inflow passages 50 can flow out of the filter 22 through the downstream small holes 55. Therefore, according to the second embodiment, the pressure loss of the filter 22 hardly increases to a value considerably larger than the potential pressure loss thereof.

Further, in the second embodiment, in the state that the amount of the ash and the particulates depositing in the inflow passages 50 increases, and then the pressure in the inflow passages 50 increases, the ash is discharged from the filter 22 through the downstream small holes 55 by the pressure in the inflow passages 50. Therefore, according to the second embodiment, the amount of the ash depositing on the filter 22 is maintained small at all times and, thus, it is not necessary to perform any special process for removing the ash from the filter 22 many times.

Furthermore, in the second embodiment, in the state that many particulates deposits in the inflow passages

50, and thus the exhaust gas does not easily pass through the partitions 54, the particulates newly flowing into the inflow passages 50 flow out of the filter 22 through the downstream small holes 55. Therefore, the amount of the particulates depositing in the filter 22 is maintained smaller than a constant amount. Thus, many particulates hardly burn in the filter 22 at once and, thus, the filter 22 is hardly melted by the heat derived from the burning of the particulates.

Further, the filter 22 of the second embodiment carries the oxidation material therein, and thus the depositing particulates are successively oxidized away. Therefore, in the state that many particulates deposit in the filter 22, and then some of the particulates are not collected by the filter 22 and flow out of the filter 22, that is, the particulate collection ratio of the filter 22 is small, the depositing particulates are successively oxidized away by the oxidation material, and thus some of the particulates newly flowing into the filter 22 are collected by the filter 22. Therefore, the amount of the particulates not collected by the filter 22 and flowing out thereof hardly considerably increases.

Immediately before the ash depositing in the inflow passages 50 is discharged from the filter 22 by the pressure in the inflow passages 50, the pressure in the inflow passages 50 may temporarily considerably increases. In the first embodiment, the exhaust gas newly flowing into the filter 22 flows into the outflow passages 51 through the upstream small holes 56, and then flows out of the filter 22. Therefore, the pressure in the inflow passages 50 hardly further increases.

However, in the second embodiment, until the ash is discharged from the filter 22, the pressure in the inflow passages 50, that is, the pressure loss of the filter 22 may continue to increase. Therefore, it is preferred to employ the filter of the second embodiment in the case that it is allowed that the pressure loss of the filter

temporarily increases to the relatively high level, or in the case that the high particulate collection ratio is required of the filter.

In the second embodiment, the outflow passages 51 may be completely closed by the upstream tapered wall portion 53 by pressing the die 90 onto the upstream end face of the honeycomb structure 80 to an extent larger than that of the first method for producing the filter.

The filter of the third embodiment will be explained. Figs. 10A and 10B show the filter of the third embodiment. Figs. 10A and 10B show an end view and a longitudinal cross sectional view of the filter. The structure of the filter of the third embodiment is basically the same as that of the first embodiment.

In the first embodiment, similar to the first embodiment, a small hole 56 is formed in the tip of each upstream tapered wall portion 53. However, no small hole is formed in the tip of each downstream tapered wall portion 52. That is, the inflow passages 50 are completely closed by the downstream tapered wall portions 52. Thus, the particulate collection ratio of the filter of the third embodiment is larger than that of the first embodiment.

In the third embodiment, in the state that the ash and the particulates deposit in the inflow passages 50, and thus the exhaust gas does not easily pass through the partitions 54, the exhaust gas newly flowing into the filer 22 may flow out of the filter 22 through the upstream small holes 56. Therefore, according to the third embodiment, even if the pressure loss of the filter increases, the pressure loss of the filter hardly increases to a value considerably larger than the potential pressure loss thereof.

Further, in the third embodiment, as explained above, in the case that the ash and the particulates deposit in the inflow passages 50, and thus the exhaust gas does not pass through the partitions 54, much exhaust

gas flows out of the filter 22 through the upstream small holes 56 and the outflow passages 51. That is, part of the ash newly flowing into the filter is discharged from the filter 22 through the upstream small holes 56 and the outflow passages 51. Therefore, it takes long time until the amount of the ash depositing in the inflow passages 50 becomes larger than the allowed amount. Thus, it is not necessary to perform a special process for removing the ash depositing in the filter 22 many times.

Further, in the third embodiment, as explained above, in the case that the ash and the particulates deposit in the inflow passages 50 and thus the exhaust gas does not easily pass through the partitions 54, much exhaust gas flows into the outflow passages 51 through the upstream small holes 56 and flows out of the outflow passages 51. That is, part of the particulates newly reaching the filter 22 flows into the outflow passages 51 through the upstream small holes 56 and flows out of the outflow passages 51. Therefore, it takes long time until the amount of the particulates depositing in the inflow passages 50 becomes larger than an allowed amount. Thus, the filter 22 is hardly melted by the heat derived from the burning of the particulates.

The filter 22 of the third embodiment carries the oxidation material therein. Therefore, by the time that the amount of the particulates depositing in the inflow passages 50 becomes larger than the allowed amount, the depositing particulates are oxidized and removed by the oxidation material. Thus, the amount of the depositing particulates hardly becomes larger than the allowed amount.

It is preferred to employ the filter of the third embodiment in the case that the exhaust gas contains a small amount of the ash and the large pressure loss of the filter is allowed, or in the case that the high particulate collection ratio is required of the filter. Further, in the third embodiment, the inflow passages 50

are completely closed by pressing the die 90 onto the downstream end face of the honeycomb structure 80 to the extent larger than that in the first method for producing the filter.

A control of the engine provided with the filter of the present invention will be explained. Fig. 11 shows a compression ignition type engine provided with the filter of the present invention. Note that the filter of the present invention may be applied to a plug ignition type engine.

Referring to Fig. 11, 1 shows an engine body, 2 a cylinder block, 3 a cylinder head, 4 a piston, 5 a combustion chamber, 6 an electrically controlled fuel injector, 7 an intake valve, 8 an intake port, 9 an exhaust valve, and 10 an exhaust port. The intake port 8 is connected through a corresponding intake branch pipe 11 to a surge tank 12. The surge tank 12 is connected through an intake duct 13 to a compressor 15 of an exhaust turbocharger 14.

A throttle valve 17 driven by a stepping motor 16 is arranged in the intake duct 13. An intercooler 18 for cooling the intake air passing the intake duct 13 is arranged around the intake duct 13. In the engine shown in Fig. 11, an engine cooling water is supplied to the intercooler 18, and cools the intake air.

The exhaust port 10 is connected to an exhaust turbine 21 of the exhaust turbocharger 14 through an exhaust manifold 19 and an exhaust pipe 20. The outlet of the exhaust turbine 21 is connected to a casing 23 housing a particulate filter 22 through an exhaust pipe 20a.

The exhaust manifold 19 is connected to the surge tank 12 through an EGR passage 24. An electrically controlled EGR control valve 25 is arranged in the EGR passage 24. Further, an EGR cooler 26 for cooling the EGR gas passing through the EGR passage 24 is arranged around the EGR passage 24. In the engine shown in Fig.

11, the engine cooling water is supplied to the EGR cooler 26 and cools the EGR gas.

On the other hand, each fuel injector 6 is connected to the fuel reservoir, that is, a common rail 27 through a fuel supply tube 6a. Fuel is supplied to the common rail 27 from an electrically controlled variable discharge fuel pump 28. Fuel supplied to the common rail 27 is supplied to the fuel injectors 6 through the fuel supply tubes 6a. A fuel pressure sensor 29 for detecting the fuel pressure in the common rail 27 is attached to the common rail 27. The amount of discharge of fuel from the fuel pump 28 is controlled such that the fuel pressure in the common rail 27 is maintained at a target fuel pressure on the basis of the output signal of the fuel pressure sensor 29.

An electronic control unit 30 is comprised of a digital computer and is provided with a read only memory (ROM) 32, a random access memory (RAM) 33, a microprocessor (CPU) 34, an input port 35, and an output port 36. The output signal of the fuel pressure sensor 29 is input to the input port 35 through the corresponding AD converters 37. A temperature sensor 39 for detecting the exhaust gas temperature is attached to the filter 22. The output signal of the temperature sensor 39 is input to the input port 35 through the corresponding AD converter 37.

A load sensor 41 is connected to an accelerator pedal 40. The sensor 41 generates an output voltage proportional to the amount of depression L of the accelerator pedal 40. The output voltage of the sensor 41 is input to the input port 35 through a corresponding AD converter 37. Further, a crank angle sensor 42 for generating an output pulse each time a crankshaft rotates by, for example, 30° is connected to the input port 35. On the other hand, the output port 36 is connected to the fuel injectors 6, the stepping motor 16, the EGR control valve 25 and the fuel pump 28 through corresponding drive

circuits 38.

As explained above, in the state that the particulates deposit in layers in the filter 22, even if the amount M of the inflowing particulates becomes smaller than the amount G of the particulates removable by oxidation, the active oxygen does not easily oxidize the particulates. In particular, immediately after the engine starts up, the filter temperature TF is low. At this time, the amount M of the inflowing particulates is larger than the amount G of the particulate removable by oxidation. In the state that the portions of the particulates not oxidized start to remain, in other words, in the state that the amount of the depositing particulates is smaller than an allowed upper limit, if the amount M of the inflowing particulates becomes smaller than the amount G of the particulates removable by oxidation, the remaining portions of the particulates are oxidized and removed by the active oxygen without emitting a luminous flame.

Therefore, in the present invention, the amount M of the inflowing particulates and the filter temperature TF are maintained such that the amount M of the inflowing particulates is smaller than the amount G of the particulates removable by oxidation. In addition, in the present invention, the amount M of the inflowing particulates and the filter temperature TF are maintained such that the remaining portions 63 of the particulates hardly cover the surface of the carrier layer as shown in Fig. 7B even if the amount M of the inflowing particulates temporarily becomes larger than the amount G of the particulates removable by oxidation, in other words, such that the amount of the particulates depositing in layers is maintained smaller than an allowed limit, and the particulates may be oxidized and removed when the amount M of the inflowing particulates becomes smaller than the amount G of the particulates removable by oxidation.

However, even if the amount M of the inflowing particulates and the filter temperature TF are controlled as explained above, the particulates may deposit in layers in the filter 22. In this case, the particulates depositing in the filter 22 may be oxidized and removed without emitting a luminous flame by temporarily making the air fuel ratio of part or entire of the exhaust gas rich.

That is, when the air fuel ratio of the exhaust gas is maintained lean for a while, much oxygen adheres to the platinum. Therefore, the catalytic action of the platinum decreases. However, if the air fuel ratio of the exhaust gas is made rich to decrease the concentration of oxygen in the exhaust gas, the oxygen is removed from the platinum, and thus the catalytic action of the platinum increases. Therefore, when the air fuel ratio of the exhaust gas is made rich, much active oxygen is easily discharged from the active oxygen production agent 61 to the outside at once. Thus, the depositing particulates are reformed by the active oxygen at once to the easily oxidizable state, and then the particulates burn away. Therefore, when the air fuel ratio of the exhaust gas is made rich, the amount G of the particulates removable by oxidation increases.

In this case, the air fuel ratio of the exhaust gas may be made rich when the particulates deposit in layers in the filter 22. Otherwise, the air fuel ratio of the exhaust gas may be periodically made rich independent of whether the particulates deposit in layers.

For example, the air fuel ratio of the exhaust gas is made rich by controlling the quantity of the fuel injected from the injector 6 such that the average air fuel ratio of the mixture in the combustion chamber 5, while the valve lifts of the throttle valve 17 and the EGR control valve 25 are controlled such that the EGR rate (the quantity of the EGR gas/(the quantity of the intake air + the quantity of the EGR gas)) is maintained

larger than 65 percent when the engine load is small.

As explained above, in the case that the particulates are oxidized away by making the air fuel ratio of the exhaust gas rich when the particulates deposit in the filter 22 and are not easily oxidized away, the filter 22 of the present invention has an advantage that hydrocarbon (HC) hardly adheres to the upstream area of the filter 22.

That is, if the air fuel ratio of the exhaust gas is made rich, the hydrocarbon flows into the filter 22. At this time, the hydrocarbon easily adheres to the upstream area of the filter 22. As the temperature at the upstream area of the filter 22 is lower than that at its downstream area, the hydrocarbon adheres to the filter 22 at its upstream area and is not easily consumed. Thus, the hydrocarbon deposits on the upstream area of the filter 22. However, in the present invention, since the filter 22 carries much oxidation material at its upstream area, the hydrocarbon is consumed and is hardly deposits thereon. Therefore, the hydrocarbon hardly closes the upstream area of the filter 22.

Fig. 12 shows an example of the routine of the engine operation control explained above. Referring to Fig. 12, first, at step 100, it is judged if the average air fuel ratio of the mixture in the combustion chamber 5 should be made rich. When it is not necessary to make the average air fuel ratio of the mixture in the combustion chamber 5 rich, the valve lift of the throttle valve 17 is controlled at step 101, the valve lift of the EGR control valve 25 is controlled at step 102, and the quantity of the fuel injected from the injector 6 is controlled at step 103 such that the amount M of the inflowing particulates becomes smaller than the amount G of the particulates removable by oxidation.

On the other hand, when it is judged that the average air fuel ratio of the mixture in the combustion chamber 5 should be made rich at step 100, the valve lift

of the throttle valve 17 is controlled at step 104 and the valve lift of the EGR control valve 25 at step 105 such that the EGR rate becomes larger than 65 percent, and the quantity of the fuel injected from the injector 6 is controlled at step 106 such that the average air fuel ratio of the mixture in the combustion chamber 5 becomes rich.

Fuel or lubrication oil contains calcium (Ca). Therefore, the exhaust gas contains calcium. Calcium produces calcium sulfate ($CaSO_4$) in the presence of SO3. The calcium sulfate is a solid and will not break down by heat even at a high temperature. Therefore, if calcium sulfate is produced, the calcium sulfate closes the fine pores of the filter 22. In this case, the exhaust gas does not easily pass through the filter 22.

In this case, if an alkali metal or an alkali earth metal having an ionization tendency higher than that of calcium, for example potassium (K), is used as the active oxygen production agent 61, the SO3 diffusing in the agent 61 bonds with the potassium to become potassium sulfate (K_2SO_4). On the other hand, the calcium does not bond with the SO3, and then passes through the partitions 54 of the filter 22 and flows into the outflow passages 50. Therefore, there is no longer any clogging of the fine pores of the partitions 54. Thus, as explained above, it is preferable to use an alkali metal or an alkali earth metal having an ionization tendency higher than calcium, that is, potassium, lithium, cesium, rubidium, barium, and strontium, as the active oxygen production agent 61.

The present invention may be applied to a filter comprising only precious metal such as platinum carried on the carrier layer formed therein. In this case, the solid line denoting the amount G of the particulates removable by oxidation slightly moves to the right side in Fig. 8. Further, in this case, NO_2 or SO_3 carried on the surface of the platinum produces the active oxygen.

Furthermore, as the active oxygen production agent, a catalyst may be used, which adsorbs and carries NO_2 or SO_3, and produces the active oxygen from the carried NO_2 or SO_3.

The fourth embodiment will be explained. As shown in Fig. 13, in the fourth embodiment, an oxidation catalyst 22a is arranged in the exhaust passage downstream of the outlet portion of the exhaust turbine 21 and upstream of the filter 22. The catalyst 22a is housed in a casing 23a. A temperature sensor 39a for detecting the temperature of the catalyst 22a is attached to the catalyst 22a. The output signal of the sensor 39a is input into the input port 37 through the corresponding AD converter 39a.

The oxidation catalyst 22a is, for example, formed by coating thin layers of alumina on the carrier formed of ceramics such as cordierite, or heat resistant steel, and then applying the precious metal catalyst to the alumina layer. The precious metal catalyst has an oxidation ability, and thus the catalyst 22a may strongly oxidize specific constituents, in particular, hydrocarbon and carbon monoxide ($2CO + O \rightarrow CO_2$, $HC + O_2 \rightarrow CO_2 + H_2O$) away.

The oxidation catalyst 22a carries has an amount of the precious metal catalyst per unit surface area larger than that carried by the filter 22. In the catalyst 22a of the fourth embodiment, one or more of platinum, palladium and rhodium is used as the precious metal catalyst. Further, in the fourth embodiment, in addition to the precious metal catalyst, an oxygen storage agent such as cerium or nickel for absorbing and releasing the oxygen may be carried on the alumina carrier. Furthermore, in the fourth embodiment, in addition to the precious metal catalyst, a stabilization agent such as barium, lanthanum, or zirconium for preventing the change of the alumina and the precious metal catalyst by heat.

As shown in Fig. 14, the oxidation catalyst 22a

comprises a honeycomb carrier. Therefore, the catalyst 22a has a plurality of exhaust gas passages 22b therein, which are defined by partitions 22c and extend parallel to each other. Further, the inlet and outlet openings of the exhaust gas passages 22b of the catalyst 22a are completely open. That is, the catalyst 22a is a monolith type catalyst. In the catalyst 22a, the exhaust gas is not forced to pass through the partitions 22c, and thus the catalyst 22a has a small pressure loss. Therefore, the catalyst 22a arranged upstream of the filter 22 increases the pressure loss of the exhaust gas purification device to only a small extent.

The exhaust gas contains particulates such as soot and Soluble Organic Fraction (SOF) therein. The fuel is smothered in the state that the oxygen is not sufficient in the combustion chamber. The soot is produced from the smothered fuel and mainly consists of carbon (C). On the other hand, the fuel and the hydrocarbon contained in the engine oil are evaporated by the high temperature in the combustion chamber and then deposit to become particulate matters by the decreasing of the temperature in the combustion chamber. The SOF is the depositing particulate matter and mainly consists of hydrocarbon.

If the atmosphere surrounding the precious metal catalyst carried in the filter 22 is oxidative, the catalyst strongly oxidizes the material contained in the exhaust gas. Therefore, if the engine is a compression ignition type engine, the lean exhaust gas is discharged therefrom, and thus the precious metal catalyst demonstrates a strong oxidizablity. Therefore, the SOF contained in the exhaust gas is oxidized away by the oxidizability of the catalyst ($C_mH_n + O_2 \rightarrow CO_2 + H_2O$). Of course, the SOF contained in the exhaust gas is oxidized away by the active oxygen released from the active oxygen production agent 61 ($C_mH_n + O^* \rightarrow CO_2 + H_2O$).

However, depending on the engine operation state,

the concentration of the SOF in the exhaust gas discharged from the combustion chamber 5 may temporarily increase. In this case, the concentration of the SOF in the exhaust gas reaching the filter 22 increases, and thus much SOF adheres to the upstream tapered wall portions 53 per unit time. The amount of the SOF removable by oxidation per unit time at the upstream tapered wall portions 53 is limited. Therefore, if the concentration of the SOF in the exhaust gas reaching the filter 22 increases, the SOF adhering to the upstream tapered wall portions 53 is not completely oxidized away, and then the SOF deposits thereon. Therefore, the SOF closes the upstream small holes 56.

In the filter 22, the upstream small holes 56 have sizes larger than those of the fine pores of the upstream tapered wall portion 53 or the partition 54, and the partitions 54 extend generally parallel to the flow direction of the exhaust gas. However, the upstream small holes 56 open to a direction perpendicular to the flow direction of the exhaust gas. Therefore, the quantity of the exhaust gas passing through the upstream holes 56 per unit surface area is larger than that passing through the upstream tapered wall portions 53 or the partitions 54 per unit surface area. In addition, since the upstream small holes 56 are located at the most upstream area of the filter 22, the particulates contained in the exhaust gas passing through the upstream small holes 56 have not been oxidized away. Therefore, the amount of the SOF passing through the upstream small holes 56 is larger than that passing through the upstream tapered wall portions 53 or the partitions 54. Thus, the SOF easily closes the upstream small holes 56.

Further, the soot has no viscosity, and thus normally does not close the upstream small holes 56, and then passes through the holes 56. On the other hand, the SOF has viscosity. Therefore, if the SOF adheres to the upstream tapered wall portions 53, the soot adheres to

the SOF, and then closes the upstream small holes 56.

Furthermore, the SOF in the exhaust gas is oxidized away by the filter 22 before the SOF reaches the downstream small holes 55. Therefore, the SOF hardly closes the holes 55. However, if the particulates deposit in the filter 22, or the concentration of the SOF in the exhaust gas discharged from the engine increases, or the filter temperature does not rise at the engine start up to an extent that the filter demonstrates its oxidizability, the rate of oxidation of particulates by the filter 22 decreases. In this case, the filter 22 does not completely oxidize the particulates away. Therefore, much SOF reaches the downstream small holes 55. In this case, for the same reasons as those in connection with the upstream small holes 56, the SOF closes the downstream small holes 55.

Opposed to this, in the fourth embodiment, the oxidation catalyst 22a is arranged upstream of the filter 22. The catalyst 22a strongly oxidizes and removes the SOF contained in the exhaust gas ($C_mH_n + O_2 \rightarrow C_2O + H_2O$). Therefore, the amount of the SOF contained in the exhaust gas is decreased before the exhaust gas flows into the filter 22. If the exhaust gas flowing into the filter 22 contains almost no SOF, the SOF hardly deposits around the small holes 55,56, and hardly closes them.

Note that, in the case that the engine is designed to inject the fuel into the exhaust gas on the basis of the total amount of the NOx carried by the active oxygen production agent 61 of the filter 22 in order to reduce the NOx carried by the agent 61, the concentration of the SOF in the exhaust gas increases as explained above when fuel is injected into the exhaust gas.

Further, note that, in the case that the engine is designed that the fuel combustion temperature in the combustion chamber becomes lower than the soot generation temperature by circulating the exhaust gas through the EGR passage by a quantity larger than that wherein the

generation amount of the soot is peak, the concentration of the SOF in the exhaust gas increases as explained above when the exhaust gas is circulated into the intake passage by a quantity larger than that wherein the generation amount of the soot is peak. In this case, the quantity of the intake air, i.e., the oxygen decreases, and thus the fuel does not easily burn in the combustion chamber 5. Therefore, the concentration of the SOF in the exhaust gas increases.

The fifth embodiment will be explained. In the above explained fourth embodiment, the sizes of the holes 55,56 are generally the same as each other. Opposed to this, in the fifth embodiment, as shown in Figs. 15A and 15B, the sizes of the holes 55,56 are different from each other. In detail, in the fifth embodiment, the sizes of the upstream holes 56 successively increase from a central region of the filter 22 to a peripheral region thereof. The central region is the region around the axis of the filter 22 corresponding to the axis of the housing of the turbine, i.e., of the exhaust pipe. On the other hand, the peripheral region is the region around the central region of the filter 22 and adjacent to the periphery of the filter 22. Further, the sizes of the downstream holes 55 successively increase from the central region of the filter 22 to the peripheral region thereof.

In the fifth embodiment, in order to maintain the pressure loss of the filter 22 small, the casing 23 hosing the filter 22 has a diameter larger than that of the exhaust pipe connected thereto. Further, the casing 23 is connected to the exhaust pipe such that the central axis of the casing 23 aligns with that of the exhaust pipe. Furthermore, the casing 23 is smoothly connected to the exhaust pipe by the conical portion of the casing 23. In this structure, the exhaust gas flowing into the casing 23 from the exhaust pipe easily flows into the central region of the filter 22, and does not easily flow

into the peripheral region thereof. Therefore, the quantity of the exhaust gas flowing in the central region of the filter 22 is larger than that flowing in the peripheral region thereof. Thus, the distribution of the exhaust gas flowing in the filter 22 is not uniform.

Opposed to this, in the fifth embodiment, the small holes 55,56 at the central region of the filter 22 have sizes larger than those at the peripheral region thereof. If the small holes have large sizes, the exhaust gas easily passes through the small holes. Therefore, in the fifth embodiment, the difference in quantity of the exhaust gas flowing in the central region of the filter 22 and the peripheral region thereof decreases. That is, as explained above, the exhaust gas reaching the filter 22 easily flows into the central region of the filter 22. However, in the fifth embodiment, the small holes 55,56 at the peripheral region of the filter 22 are enlarged. Therefore, the exhaust back pressure in the peripheral region of the filter 22 is small, and thus the exhaust gas easily flows thereinto. Therefore, the distribution of the exhaust gas is more uniform. Accordingly, the exhaust gas uniformly passes through the filter 22, and thus the filter 22 is efficiently used.

The filter 22 is heated mainly by heat derived from the exhaust gas, and from the chemical reaction, in the filter 22, between the specific components contained in the exhaust gas. The quantity of the heat for heating the filter 22 is proportional to the quantity of the exhaust gas flowing into the filter 22. Therefore, the temperature of each portion of the filter 22 depends on the quantity of the exhaust gas flowing thereinto.

In the case that the sizes of the small holes 55,56 of the filter 22 are the same as each other and the cross sectional areas of the exhaust gas passages 50,51 of the filter 22 are the same as each other, the exhaust gas more easily flows into the central region of the filter 22 than into the peripheral region thereof. Therefore,

the filter 22 has a temperature at its peripheral region lower than that at its central region. Further, the peripheral wall surface of the filter 22 is exposed to the atmosphere having a low temperature. Therefore, the heat is discharged from the peripheral region of the filter 22 to the atmosphere. Thus, the filter 22 has a temperature at its peripheral region lower than that at its central region. Since an ability to oxidize the particulates at each region of the filter 22 is proportional to the temperature thereof, the particulate oxidation ability is large around the small holes 55,56 at the central region of the filter 22, and thus the particulates do not easily close the small holes 55,56 at this region. On the other hand, at the peripheral region of the filter 22, the particulate oxidation ability is small around the small holes 55,56, and thus the particulates easily close the holes 55,56 in this region.

Opposed to this, in the fifth embodiment, the sizes of the small holes 55,56 successively increase from the central region of the filter 22 to the peripheral region thereof. Therefore, the exhaust gas uniformly flows in the filter 22, and thus the distribution of the temperature of the filter 22 is uniform. Accordingly, at the central region of the filter 22, the small holes 55,56 have small sizes but the tapered wall portions 52,53 around the small holes 55,56 have high temperatures. Therefore, the particulate oxidation ability at the central region of the filter 22 is large, and thus the particulates do not easily close the small holes 55,56 at this region. On the other hand, at the peripheral region of the filter 22, the tapered wall portions 52,53 around the small holes 55,56 have low temperatures but the small holes 55,56 have large sizes. Therefore, the particulates do not easily close the small holes 55,56 at the peripheral region of the filter 22.

As explained above, when the amount of the particulates depositing in the filter 22 becomes large,

it is necessary to perform a control for raising the temperature of the filter 22 to a certain temperature to oxidize the depositing particulates away from the filter 22. Further, when the amount of the SO_2 carried by the filter 22 is large, it is necessary to perform control for raising the temperature of the filter 22 to a certain temperature to discharge the carried SO_2 from the filter 22. However, on performing the above control, if the filter 22 has a difference in temperature, the temperature of the portion originally having a low temperature may not reach a target temperature, or the temperature of the portion originally having a high temperature may excessively increase beyond the target temperature. In particular, in the case that the temperature of the portion originally having a high temperature excessively increases beyond the target temperature, an energy is wasted, and in some cases, the filter 22 is melted by the high temperature.

Opposed to this, in the fifth embodiment, the difference in temperature in the filter 22 is small. Therefore, when the temperature of the filter 22 is raised to the target temperature, the temperatures of portions of the filter 22 are hardly excessively raised to high temperatures. Therefore, the waste of the energy and the melting of the filter 22 are avoided.

Note that, in the fifth embodiment, the sizes of the holes 55,56 may increase step by step, for example, in two or three steps from the central region of the filter 22 to its peripheral region.

Note that, since the inlet and outlet openings of the exhaust gas passages of the catalyst 22 have sizes larger than those of the small holes 55,56 of the filter 22, the SOF contained in the exhaust gas hardly closes the openings of the exhaust gas passages of the catalyst 22.

Further, a catalyst which is not a monolith type catalyst may be used as the oxidation catalyst. Further,

in place of the oxidation catalyst, there may b used a catalyst for absorbing and carrying the NOx contained in the exhaust gas when the lean exhaust gas flows thereinto, and for releasing and reducing the carried NOx therefrom when the rich exhaust gas flows thereinto even if the catalyst can remove the SOF.

The sixth embodiment will be explained. Figs. 16A and 16B show an end view and a longitudinal cross sectional view of the filter of the sixth embodiment, respectively. In sixth embodiment, the sizes of the holes 55,56 of the filter 22 are generally the same as each other. However, as shown in Figs. 16A and 16B, the cross sectional areas of the exhaust gas passages 50,51 successively increase from the central region of the filter 22 to the peripheral region thereof. Accordingly, a difference between the quantities of the exhaust gas passing through the central and peripheral regions of th filter 22 is small, and thus the exhaust gas uniformly flows in the filter 22.

Therefore, for the same reasons as those explained regarding the fifth embodiment, the filter 22 has a small difference in temperature, and thus the particulates do not easily close the small holes 55,56 at the peripheral region of the filter 22. Further, since the filter 22 has a small difference in temperature, the waste of the energy and the melting of the filter are avoided when the temperature of the filter 22 is raised to the target temperature.

Note that the fifth and sixth embodiments may be combined. That is, the sizes of the small holes 55,56 of the filter 22 and the cross sectional areas of the exhaust gas passages 50,51 may successively increase from the central region of the filter 22 to the peripheral region thereof.

The seventh embodiment will be explained. As shown in Fig. 17, in the seventh embodiment, the intake passage 13 is connected to an air cleaner 43 upstream of the

throttle valve 17. Further, in the seventh embodiment, a particulate filter (hereinafter, referred to as main filter) 44 is arranged in the exhaust passage downstream of the filter 22. The main filter 44 is housed in a casing 45. A temperature sensor 46 for detecting the temperature of the main filter 44 is attached to the upstream end of the main filter 44. The output signal of the temperature sensor 46 is input into the input port 35 through the corresponding AD converter 37. In the seventh embodiment, the structure of the filter 22 is the same as the filter of the first embodiment. Hereinafter, the filter 22 is referred to as the sub-filter 22.

Referring to Figs. 18A and 18B, the main filter 44 will be explained. Figs. 18A and 18B show an end view and a longitudinal cross sectional view of the main filter, respectively. As shown in Figs. 18A and 18B, the filter 44 has a honeycomb structure, and comprises a plurality of exhaust gas passages 44a,44b extending parallel to each other. These passages are constituted by exhaust gas inflow and outflow passages 44a and 44b. The inflow passages 44a are closed at their downstream ends by plugs 44c. On the other hand, the outflow passages 44b are closed at their upstream ends by plugs 44d.

The inflow and outflow passages 44a,44b are alternatively positioned. Thin partitions 44e intervene between the inflow and outflow passages 44a,44b. Four inflow passages 44a are positioned around each outflow passage 44b.

In other words, one 44a of the adjacent passages 44a,44b is closed at its downstream end by the plug 44c, and the other passage 44b is closed at its upstream end by the plug 44d.

The main filter 44 is formed of a porous material such as ceramics such as cordierite containing fine pores, each having a predetermined average size. Therefore, as shown in Fig. 18B, the exhaust gas flows

into the inflow passages 44a, and then into the adjacent outflow passages 44b through the fine pores of the surrounding partitions 44e. When the exhaust gas flows in the passages 44a,44b, the particulates contained in the exhaust gas are collected by the wall surfaces of the partitions 44e defining the passages 44a,44b. Further, when the exhaust gas passes through the fine pores of the partitions 44e, the particulates contained in the exhaust gas are collected by the wall surfaces defining the fine pores.

Note that, similar to the sub-filter 22, the main filter 44 also carries precious metal catalyst and active oxygen production agent therein. Further, similar to the sub-filter 22, the end openings of the exhaust gas passages 44a,44b of the main filter 44 may be partially closed by tapered wall portions and have small holes at the tips of the tapered wall portions. Furthermore, the end openings of the exhaust gas passages 44a,44b of the main filter 44 may be completely closed by tapered wall portions and have no small hole at the tips of the tapered wall portions. Further, the main filter 44 may be of a monolith type such that the end openings of the exhaust gas passages 44a44b are not closed, and thus ar completely open.

As explained in connection with the first embodiment, the sub-filter 22 has a pressure loss smaller than that of the main filter 44. Therefore, although the sub-filter 22 is arranged upstream of the main filter 44, the total pressure loss of the exhaust gas purification device does not largely increase. Of course, the total particulate collection ratio of the exhaust gas purification device does not largely decrease.

As explained above, the active oxygen production agent of the main filter 44 carries the oxygen in the form of the nitrate ions when the atmosphere surrounding the agent is oxidative. That is, the agent of the main filter 44 serves as a NOx carrier agent for carrying the

NOx therein when the atmosphere surrounding the agent is oxidative. The amount of the NOx which the agent can carry therein has an upper limit. If the amount of the NOx reaches the upper limit, the agent of the main filter 44 does not newly carry the NOx, and then the NOx flows out of the main filter 44. Therefore, it is necessary to purify the NOx carried in the agent by reducing the same before the amount of the carried NOx reaches the upper limit.

The active oxygen production agent releases the oxygen carried in the form of the nitrate ions when the atmosphere surrounding the agent becomes reductive. In other words, the agent releases the NOx carried in the form of the nitrate ions when the atmosphere surrounding the agent becomes reductive. At this time, as shown in Fig. 19C, the NOx released from the agent is reduced by the hydrocarbon and the carbon monoxide contained in the exhaust gas.

In the seventh embodiment, before the amount of the carried NOx reaches an allowed upper limit, the NOx carried in the agent of the main filter 44 is reduced and purified by supplying the rich or generally stoichiometric exhaust gas to the filter 44. Note that, in consideration of this function of the filter 44, the filter 44 has a NOx catalyst comprising the NOx carrier agent and the precious metal catalyst.

Note that if the rich exhaust gas having a low concentration of the oxygen is supplied to the main filter 44, the ratio of the hydrocarbon and the carbon monoxide oxidized away by the main filter 44 is small. On the other hand, if the lean or generally stoichiometric exhaust gas is supplied to the main filter 44, the ratio of the hydrocarbon and the carbon monoxide oxidized away by the filter 44 is large. Further, Figs. 19A and 19B correspond to Figs. 6A and 6B, respectively.

As explained above, the filters 22,44 purify four kinds of components such as the particulates, the NOx,

the carbon monoxide, and the hydrocarbon, depending on the characteristics of the exhaust gas flowing thereinto. The platinum and the active oxygen production agent carried by the filters 22,44 are more active when the temperatures thereof are high. Therefore, the purification ratios of the above four kinds of the components by the filters 22,44 depend on the temperature of the exhaust gas flowing thereinto, and become large when an exhaust gas having a high temperature flows thereinto.

In the seventh embodiment, the sub-filter 22 is arranged directly downstream of the exhaust manifold 17. Therefore, the hot exhaust gas immediately after being discharged from the combustion chamber 5 flows into the sub-filter 22, and thus the temperature of the sub-filter 22 is maintained high. Of course, at the engine start up, the exhaust gas discharged from the combustion chamber 5 has a low temperature but, according to the seventh embodiment, the temperature of the sub-filter 22 is rapidly raised by the exhaust gas and is maintained high. Accordingly, in the seventh embodiment, the purification ratios of the above four kinds of components are high.

The sub-filter 22 also has an ability to oxidize the particulates, and thus the decreased amount of the particulates flows into the main filter 44. Therefore, almost all of the particulates contained in the exhaust gas may be oxidized away by the main filter 44. Otherwise, as the main filter 44 is required to oxidize small amount of the particulates, it is permitted to downscale the filter 44. Note that, in order to maintain the temperature of the sub-filter 22 higher than a certain temperature, the sub-filter 22 should be arranged near the exhaust port 10. Therefore, as shown in Fig. 20, the sub-filter 22 may be arranged in the branch pipe of the manifold 17.

The eighth embodiment will be explained. In the

eighth embodiment, as shown in Fig. 21, a bypass passage 48 which bypasses the main filter 44 extends from the exhaust pipe 47 between the sub- and main filters 22,44. The passage 48 at its upstream end is connected to the exhaust pipe 47 upstream of the main filter 44, and at its downstream end is connected to the exhaust pipe 47 downstream of the main filter 44. The bypass passage 48 and the main filter 44 are in parallel with each other. In the eighth embodiment, a switch valve 49 is arranged at the connection of the bypass passage 48 and the exhaust pipe 47 upstream of the main filter 44. The valve 49 serves to switch the flow of the exhaust gas to the main filter 44 and the bypass passage 48.

The active oxygen production agent carries the SOx contained in the exhaust gas when the lean exhaust gas flows thereinto. If the amount of the SOx carried by the agent increases, the amount of the NOx which the agent can carry decreases. Therefore, before the amount of the NOx which the agent can carry decreases under an allowed lower limit, it is necessary to release the SOx from the agent.

In the eighth embodiment, the sub-filter 22 is arranged upstream of the main filter 44. The active oxygen production agent of the sub-filter 22 carries the SOx contained in the exhaust gas when the lean exhaust gas flows thereinto, and thus the exhaust gas flowing into the maim filter 44 contains a very small amount of the SOx. Therefore, in the eighth embodiment, it is hardly necessary to release the SOx from the active oxygen production agent of the main filter 44.

The active oxygen production agent of the sub-filter 22 has an allowed upper limit to carry the SOx. Therefore, before the amount of the SOx carried by the agent of the sub-filter 22 reaches the allowed upper limit, it is necessary to release the SOx from the agent of the sub-filter 22. Next, referring to Figs. 22A and 22B, the release of the SOx from the agent of the sub-

filter 22 will be explained.

Fig. 22A shows a relationship between the temperature T of the active oxygen production agent when the atmosphere surrounding the agent is rich or generally stoichiometric, and the NOx releasing ratio f(T) and the SOx releasing ratio g(T) from the agent. Fig. 22B shows the period that the atmosphere surrounding the agent is maintained rich or generally stoichiometric, and the total NOx releasing amount and the total SOx releasing amount from the agent when the agent has a temperature lower the temperature To shown in Fig. 22A.

As can be understood from the Fig. 22A, when the agent temperature T is lower than the temperature To and the atmosphere surrounding the agent is rich or generally stoichiometric, the agent releases the NOx but hardly releases the SOx therefrom. Therefore, in state that the agent temperature T is lower than the temperature To, the agent releases a very small amount of the SOx even if the atmosphere surrounding the agent is maintained rich or stoichiometric for a long time.

In the case that the engine is a compression ignition type engine, the main filter 44 often has a temperature lower than the temperature To. Therefore, even if the rich or generally stoichiometric exhaust gas flows into the main filter 44, the active oxygen production agent of the main filter 44 hardly releases the SOx therefrom.

In the eighth embodiment, when it is necessary to release the SOx from the active oxygen production agent of the sub-filter 22, the temperature of the sub-filter 22 is raised above the temperature To and the rich exhaust gas is supplied to the sub-filter 22, or the temperature of the exhaust gas flowing into the sub-filter 22 is raised above a temperature whereat the active oxygen production agent of the sub-filter 22 releases the SOx therefrom and the rich exhaust gas is supplied.

According to this, the sub-filter 22 releases the SOx therefrom. In consideration of this function of the sub-filter 22, the sub-filter 22 serves as a SOx carrying agent for carrying the SOx contained in the exhaust gas when the lean exhaust gas flows into the sub-filter 22. Further, since the sub-filter 22 is arranged near the engine body, the temperature of the sub-filter 22 is easily raised.

In the eighth embodiment, when the sub-filter 22 releases the SOx therefrom, the switch valve 47 is positioned as shown by the chain line of the Fig. 21 such that the exhaust gas flows into the bypass passages 48. According to this, the SOx released from the sub-filter 22 hardly flows into the main filter 44. On the other hand, when the sub-filter 22 does not release the SOx therefrom, the switch valve 47 is positioned as shown by the solid line of the Fig. 21.

Note that the sub-filter 22 carries the NOx contained in the exhaust gas when the lean exhaust gas flows thereinto, and releases the carried NOx therefrom when the rich or generally stoichiometric exhaust gas flows thereinto, and reduces and removes the released NOx by hydrocarbon and carbon monoxide contained in the exhaust gas. Therefore, when the rich or generally stoichiometric exhaust gas is supplied to the sub-filter 22 to release the SOx from the sub-filter 22, the sub-filter 22 releases the NOx therefrom, and the released NOx is reduced and removed by the hydrocarbon and the monoxide contained in the exhaust gas. Therefore, even if the exhaust gas bypasses the main filter 44, the NOx, the hydrocarbon and the carbon monoxide hardly flow out of the exhaust gas purification device.

Note that, in order to stop releasing the SOx from the sub-filter 22, the air fuel ratio of the exhaust gas is changed from a rich or generally stoichiometric air fuel ratio to a lean air fuel ratio, and the position of the switch valve 47 is changed to a position shown in the

solid line of the Fig. 21.

The active oxygen production agent easily releases the SOx therefrom if the agent carries the SOx in the form of the sulfate ions or the unstable sulfate. In the eighth embodiment, as the agent of the sub-filter 22, an active oxygen production agent carrying at least one of transition metal such as copper, iron, manganese and nickel, sodium, titanium and lithium on an alumina carrier is used. Therefore, in the eighth embodiment, the agent of the sub-filter 22 easily releases the SOx therefrom.

In the eighth embodiment, in order to release the NOx from the main filter 44, the air fuel ratio of the exhaust gas is changed from the lean air fuel ratio to the rich or generally stoichiometric air fuel ratio. However, the period for maintaining the air fuel ratio of the exhaust gas lean or generally stoichiometric is short. Therefore, the temperature of the sub-filter 22 hardly rises above the temperature To. Thus, the sub-filter 22 does not release the SOx therefrom, and no SOx flows into the main filter 44. Of course, in the state that the main filter 44 has a temperature lower than the temperature To, if the exhaust gas flowing into the main filter 44 has a rich air fuel ratio, the main filter 44 releases the NOx therefrom, and the NOx is reduced and removed.

The ninth embodiment will be explained. When the air fuel ratio of the exhaust gas is made rich or generally stoichiometric to release the SOx from the sub-filter 22, some hydrocarbon or carbon monoxide flows out of the sub-filter 22. The hydrocarbon and carbon monoxide should be purified. According to the ninth embodiment, as shown in Fig. 23, in the exhaust gas purification device of the eighth embodiment, a three way catalyst 44a is arranged in the bypass passage 48. The three way catalyst 44a oxidizes the hydrocarbon and the carbon monoxide when the rich or generally stoichiometric

exhaust gas flows thereinto.

According to the ninth embodiment, when the sub-filter 22 releases the SOx therefrom, the switch valve 47 is positioned at a position shown by the chain line of the Fig. 23, and thus the hydrocarbon and the carbon monoxide flow from the sub-filter 22 into the bypass passage 48. Therefore, the hydrocarbon and the carbon monoxide are oxidized and purified by the three way catalyst. Note that it is sufficient that the catalyst arranged in the bypass passage 48 has an ability to oxidize the components such as hydrocarbon and carbon monoxide away. Therefore, an oxidation catalyst may be used in place of the three way catalyst.

The tenth embodiment will be explained. In the tenth embodiment, in place of the filter of the first embodiment, a exhaust gas purification catalyst 22 carrying a hydrocarbon collection agent is arranged in the exhaust passage of the engine. The catalyst 22 comprises the same structure as that of the filter of the first embodiment. Unburned hydrocarbon contained in the exhaust gas adheres to the hydrocarbon collection agent of the catalyst 22. In other words, the hydrocarbon collection agent collects unburned hydrocarbon contained in the exhaust gas. In the tenth embodiment, as the hydrocarbon collection agent, layers formed of, for example, alumina are entirely formed on both side wall surfaces of the partitions 54, the wall surfaces defining the fine pores of the partitions 54, and both side wall surfaces of the tapered wall portions 52,53.

The hydrocarbon collection agent collects the unburned hydrocarbon contained in the exhaust gas by the adhering of the hydrocarbon thereto when the agent has a temperature lower than the temperature at which the hydrocarbon leaves the agent. On the other hand, the hydrocarbon collection agent releases the collected hydrocarbon therefrom when the agent has a temperatur higher than the temperature at which the hydrocarbon

leaves the agent. The temperature at which th hydrocarbon leaves the hydrocarbon collection agent is set such that the agent does not release the hydrocarbon when a later explained hydrocarbon purification catalyst has a temperature lower than the temperature at which the catalyst does not oxidize and purify the unburned hydrocarbon.

The exhaust gas purification catalyst 22 has a hydrocarbon purification catalyst for oxidizing and purifying the unburned hydrocarbon. In the tenth embodiment, as the hydrocarbon purification catalyst, precious metal catalyst such as platinum is carried on the alumina carrying layer of the catalyst 22. The hydrocarbon purification catalyst oxidizes and purifies the unburned hydrocarbon when its temperature is higher than a hydrocarbon purification temperature.

In the tenth embodiment, the pressure loss of the exhaust gas purification catalyst 22 and the unburned hydrocarbon and particulate collection ratios of the catalyst 22 can be adjusted by adjusting the sizes of the small holes 55,56 of the catalyst 22.

The action of the exhaust gas purification catalyst of the tenth embodiment will be explained. Even in the state that the hydrocarbon collection agent has a low temperature, if the quantity of the exhaust gas flowing into the catalyst 22 per unit time rapidly increases, the hydrocarbon collected by the agent may be released from the wall surfaces or fine pores of the partitions 54 by the exhaust gas. At this time, the hydrocarbon purification catalyst also has a low temperature, and thus does not purify the hydrocarbon. In this case, if the exhaust gas passages of the catalyst 22 completely open at the outlets thereof, the hydrocarbon flows out of the catalyst 22.

When the catalyst 22 has a low temperature, for example, at engine start up, the hydrocarbon purification catalyst also has a temperature lower than th

hydrocarbon purification temperature, and thus the unburned hydrocarbon contained in the exhaust gas is not oxidized and purified by the hydrocarbon purification catalyst. However, at this time, the hydrocarbon collection agent has a temperature lower than the hydrocarbon release temperature, and thus the unburned hydrocarbon contained in the exhaust gas is collected by the hydrocarbon collection agent. Therefore, the unburned hydrocarbon hardly flows out of the catalyst 22.

On the other hand, when the temperature of the exhaust gas discharged from the engine successively rises and the temperature of the hydrocarbon collection agent exceeds the hydrocarbon release temperature, the unburned hydrocarbon leaves the hydrocarbon collection agent. At this time, the hydrocarbon purification catalyst has a temperature higher than the hydrocarbon purification temperature. Therefore, the unburned hydrocarbon leaving the hydrocarbon collection agent is oxidized and purified by the hydrocarbon purification catalyst. Thus, the unburned hydrocarbon hardly flows out of the catalyst 22.

In the state that the hydrocarbon collection agent has a temperature lower than the hydrocarbon release temperature, if the quantity of the exhaust gas passing through the fine pores of the partitions 54 of the catalyst 22 rapidly increases, the unburned hydrocarbon may leave the fine pores of the partitions 54. At this time, the hydrocarbon purification catalyst has a temperature lower than the hydrocarbon purification temperature, and thus the leaving hydrocarbon is hardly purified by the hydrocarbon purification catalyst.

In the tenth embodiment, the upstream openings of the outflow passages 51 of the catalyst 22 are partially closed by the upstream tapered wall portions 53, and thus almost all exhaust gas flows into the inflow passages 50 of the catalyst 22. Further, the downstream openings of the inflow passages 50 of the catalyst 22 are partially closed by the downstream tapered wall portions 52, and

thus almost all exhaust gas passes through the fine pores of the partitions 54. Therefore, the particulates ar collected in the fine pores of the partitions 54. Of course, the particulates are collected on the wall surfaces of the partitions 54 defining the inflow passages 50.

In the state that the particulates are collected and deposit in the fine pores and on the wall surfaces of the partitions 54, the exhaust gas does not easily pass through the fine pores of the partitions 54. As a result, even if the quantity of the exhaust gas flowing into the catalyst 22 per unit time rapidly increases, the quantity of the exhaust gas passing through the fine pores of the partitions 54 per unit time does not largely increase. Therefore, the unburned hydrocarbon hardly leaves the fine pores of the partitions 54. Thus, the unburned hydrocarbon hardly flows out of the catalyst 22.

Note that, similar to the filter of the first embodiment, the catalyst 22 of the tenth embodiment has an active oxygen production agent, and thus successively oxidizes the particulates away for a short time. Therefore, the amount of the particulates collected in the fine pores of the partitions 54 and on the wall surfaces of the partitions 54 defining the inflow passages 50 is maintained small.

As explained above, the concentration of the oxygen around the active oxygen production agent decreases when the particulates adhere to the agent even in the state that the atmosphere surrounding the agent 61 is lean. Further, other than this case, the concentration of the oxygen around the active oxygen production agent decreases when the rich exhaust gas flows into the exhaust gas purification catalyst 22, and thus the atmosphere surrounding the agent becomes rich.

As explained above, in the state that the atmosphere surrounding the active oxygen production agent is lean, when the particulates adhere to the agent to decrease the

concentration of the oxygen therearound, the NOx leaves the agent. In this case, the leaving NOx is carried again by the active oxygen production agent. On the other hand, as explained above, when the rich exhaust gas flows into the catalyst 22 to make the atmosphere surrounding the active oxygen production agent rich, the NOx leaves the agent. In this case, the leaving NOx is reduced and purified by the unburned hydrocarbon contained in the exhaust gas together with the action of the platinum. That is, if the engine operation is controlled to discharge the rich exhaust gas therefrom, the NOx carried by the active oxygen production agent is reduced and purified. Therefore, the catalyst 22 of the tenth embodiment has a NOx catalyst comprising the active oxygen production agent and the platinum.

Note that, as explained above, in the case that the catalyst 22 has an active oxygen production agent, the catalyst 22 oxidizes the particulates collected therein away even if the catalyst 22 has a low temperature. However, if the catalyst 22 has a lower temperature, the particulates successively deposit in the catalyst 22. As explained above, the inlets of the inflow passages 50 and the outlets of the outflow passages 51 of the catalyst 22 are defined by the wall surfaces of the tapered wall portions 52,53, and thus the exhaust gas does not flow with turbulence at the inlets of the inflow passages 50 and the outlets of the outflow passages 51. Therefore, the catalyst 22 potentially has a low pressure loss. Thus, even if the particulates deposit in the catalyst 22, the pressure loss of the catalyst 22 is maintained low.

Of course, if the amount of the unburned hydrocarbon collected by the hydrocarbon collection agent or the amount of the particulates depositing in the catalyst 22 increases, the ability of the collection of the unburned hydrocarbon by the hydrocarbon collection agent decreases. However, for example, after the engine starts

up, the temperature of the catalyst 22 rises, and thus the unburned hydrocarbon and the particulates collected in the catalyst 22 are oxidized. Therefore, at the next engine start up, the very small amount of the unburned hydrocarbon and the particulates deposit in the catalyst 22. Thus, the unburned hydrocarbon leaving the catalyst 22 immediately after the engine start up is assuredly collected by the hydrocarbon collection agent of the catalyst 22.

In the tenth embodiment, almost all exhaust gas flows into the inflow passages 50 of the catalyst 22, passes through the fine pores of the partitions 54, and flows into the outflow passages 51. When the exhaust gas passes through the fine pores of the partitions 54, some particulates are collected in the fine pores of the partitions 54. If the particulates are collected in the fine pores of the partitions 54, the exhaust gas does not easily pass through the partitions 54. Therefore, even if the quantity of the exhaust gas flowing into the catalyst 22 rapidly increases, the quantity of the exhaust gas passing through the fine pores of the partitions 54 does not largely increase. Thus, the unburned hydrocarbon hardly leaves the fine pores of the partitions 54.

Therefore, in the state that the hydrocarbon collection agent has a temperature lower than the hydrocarbon release temperature and the hydrocarbon purification catalyst has a temperature lower than the hydrocarbon purification temperature, the unburned hydrocarbon hardly leaves the fine pores of the partitions 54 even if the quantity of the exhaust gas flowing into the catalyst 22 rapidly increases. That is, in the tenth embodiment, in the state that the hydrocarbon purification catalyst does not purify the unburned hydrocarbon, even if the quantity of the exhaust gas flowing into the catalyst 22 per unit time rapidly increases, almost all unburned hydrocarbon remains on the

hydrocarbon collection agent.

The second method for producing a particulate filter of the invention will be explained. The method explained below is a method for producing a particulate filter 22 shown in Figs. 24A and 24B. The filter 22 shown in Figs. 24A and 24B is the same as that shown in Figs. 1A and 1B except that each tapered wall portion of the filter shown in Figs. 24A and 24B have a quadrangular pyramid shape while each tapered wall portion of the filter shown in Figs. 1A and 1B have a conical shape.

According to the second method, first, as shown in Figs. 25A and 25B, a substrate 100 formed of porous material such as cordierite and having a honeycomb structure is prepared. The substrate 100 has exhaust gas passages 50,51 defined by partitions 54. The partitions 54 form a gridiron pattern.

Next, as shown in Fig. 25B, a closure device 101 for partially closing end openings of the exhaust gas passages 50,51 is pressed onto one of the end faces of the substrate 100. Figs. 26A and 26B show the closure device 101 in detail. Referring to Fig. 26A showing a plan view of the closure device 101, the device 101 has predetermined numbers of projections 102. As can be understood from Fig. 26B showing one of the projections 102, each projection 102 has substantially a regular quadrangular pyramid shape. The projections 102 are arranged in a pattern that four adjacent ridges 103 of four adjacent projections 102 converge. Further, a pin 104 is arranged at each area where four adjacent ridges 103 of four adjacent projections 102 converge.

The closure device 101 is pressed onto one of the end faces of the substrate 100 such that each projection 102 is inserted into the corresponding exhaust gas passage 50. When the device 101 is pressed onto one end face of the substrate 100, four end portions of four adjacent partitions 54 defining each exhaust gas passage 51 are gathered toward each other by corresponding four

adjacent projections 102. Each pin 104 of the closure device 101 exists in each area enclosed by four gathered end portions of four adjacent partitions 54. As a result, four end portions of four adjacent partitions 54 defining each exhaust gas passage 51 are partially connected to each other while a small hole 56 is formed therein by the pin 104. Thus, upstream tapered wall portions 53 having the small holes 56 are formed.

Next, the closure device 101 is pressed onto the other end face of the substrate 100 such that each projection 102 is inserted into each exhaust gas passage 51. Thus, downstream tapered wall portions 52 having small holes 55 are formed.

As explained above, according to the second method, the closure of the end openings of the exhaust gas passages, i.e., the formation of the tapered wall portions for closing the end openings of the exhaust gas passages, and the formation of the small holes in the tapered wall portions are performed at a time.

The third method for producing a filter will be explained. The closure device 101 used in the third method comprises an opening closure device 105 shown in Fig. 27A and a hole formation device 106 shown in Fig. 28A.

Referring to Fig. 27A showing a plan view of the opening closure device 105, the device 105 has predetermined numbers of projections 102. Fig. 27B shows one of the projections 102. As can be understood from Fig. 27B, each projection 102 has substantially a regular quadrangular pyramid shape. Each projection 102 is arranged in a pattern that four adjacent ridges 103 of four adjacent projections 102 converge.

On the other hand, referring to Fig. 28A showing a plan view of the hole formation device 106, the device 106 has predetermined numbers of pins 104. Fig. 28B shows four pins 104. Each pin 104 is arranged at each area where four adjacent ridges 103 of four adjacent

projections 102 converge.

According to the third method, as shown in Fig. 29A, first, the opening closure device 105 is pressed onto one of the end faces of the substrate 100 such that each projection 102 is inserted into each exhaust gas passage 50. When the device 105 is pressed onto one end face of the substrate 100, four end portions of four adjacent partitions 54 defining each exhaust gas passage 51 are gathered toward each other by corresponding four adjacent projections 102. Thus, four end portions of four adjacent partitions 54 defining each exhaust gas passage 51 are connected to each other to completely close the end opening of each exhaust gas passage 51 by a corresponding tapered wall portion.

Next, as shown in Fig. 29B, the hole formation device 106 is pressed onto one end face of the substrate 100 such that each pin 104 pierces the tip of the corresponding tapered wall portion which completely closes the end opening of the corresponding exhaust gas passage 51. As a result, a small holes 56 is formed in the tip of each tapered wall portion.

Regarding the other end face of the substrate 100, the similar processes are performed. That is, the opening closure device 105 is pressed onto the other end face of the substrate 100 such that each projection 102 is inserted into the corresponding exhaust gas passage 51. As a result, the end opening of each exhaust gas passage 50 is completely closed by a corresponding tapered wall portion. Next, the hole formation device 106 is pressed onto the other end face of the substrate 100 such that each pin 104 pierces the tip of the corresponding tapered wall portion which completely closes the end opening of the corresponding exhaust gas passage 50. As a result, a small hole 55 is formed in the tip of each tapered wall portion.

According to the third method, first, the closure of the end openings of the exhaust gas passages, i.e., the

formation of the tapered wall portions for closing the end openings of the exhaust gas passages is performed, and thereafter the formation of the small holes in the tapered wall portions is performed. Of course, in the third method, the following may be employed. That is, first, the end openings of the exhaust gas passages 50 are completely closed by the tapered wall portions, and then the end openings of the exhaust gas passages 51 are completely closed by the tapered wall portions, and then the small holes are formed in the tapered wall portions.

The fourth method for producing a filter will be explained. As shown in Fig. 30, the closure device 101 used in the fourth method comprises an opening closure device 107 and a hole formation device 108.

Similar to the opening closure device 105 as shown in Fig. 29A, the opening closure device 107 has predetermined numbers of projections 102. Similar to the device 105, each projection 102 of the device 107 has substantially a regular quadrangular pyramid shape, and the projections 102 are arranged in a pattern that four adjacent ridges 103 of four adjacent projections 102 converge. Unlike the device 105, the device 107 has through holes 109. Each hole 109 is positioned at each area where four adjacent ridges 103 of four adjacent projections 102 converge.

On the other hand, similar to the hole formation device 106 shown in Figs. 28A and 28B, the hole formation device 108 has predetermined numbers of pins 104. The pins 104 are arranged in a pattern that each pin 104 is inserted into the corresponding through hole 109.

According to the fourth method, similar to the third method, first, the opening closure device 107 is pressed onto one of the end faces of the substrate 100 such that each projection 102 is inserted into the corresponding exhaust gas passage 50. As a result, the end opening of each exhaust gas passage 51 is completely closed by a corresponding tapered wall portion.

Next, in the state that the device 107 is pressed onto one end face of the substrate 100, the hole formation device 108 is pressed onto the device 107 such that each pin 104 is inserted into the corresponding through hole 109. As a result, each pin 104 pierces the tip of the corresponding tapered wall portion which completely closes the end opening of the corresponding exhaust gas passage 51. As a result, a small hole 56 is formed in the tip of each tapered wall portion.

Regarding the other end face of the substrate 100, the similar processes are performed. That is, similar to the third method, the opening closure device 107 is pressed onto the other end face of the substrate 100 such that each projection 102 is inserted into the corresponding exhaust gas passage 51. As a result, the end opening of each exhaust gas passage 50 is completely closed by a corresponding tapered wall portion. Next, in the state that the device 107 is pressed onto the other end face of the substrate 100, the hole formation device 108 is pressed onto the device 107 such that each pin 104 is inserted into the corresponding through hole 109. As a result, each pin 104 pierces the tip of the corresponding tapered wall portion which completely closes the end opening of the corresponding exhaust gas passage 50. Thus, a small hole 55 is formed in the tip of each tapered wall portion.

According to the fourth method, similar to the third method, first, the closure of the end openings of the exhaust gas passages, i.e., the formation of the tapered wall portions for closing the end openings of the exhaust gas passages is performed, and then the formation of the small holes in the tapered wall portions is performed.

According to the fourth method, in the state that the tapered wall portions of the substrate 100 are pressed by the device 107, each small hole is formed in the corresponding tapered wall portion by the device 108. Therefore, when each pin 104 of the device 108 is pressed

onto the corresponding tapered wall portion, the tapered wall portions are hardly subject to damage.

Further, in the above explained third method, after the tapered wall portions are formed, the small holes are formed by pressing the hole formation device 106 onto the end face of the substrate 100. Therefore, before the device 106 is pressed onto the end face of the substrate, it is necessary to exactly position the device 106 such that each pin 104 of the device 106 corresponds to the tip of the corresponding tapered wall portion. This is burdensome. Opposed to this, according to the fourth method, each small hole is formed in the corresponding tapered wall portion simply by inserting each pin 104 of the device 108 into the corresponding through hole 109 of the device 107. Therefore, it is not necessary to perform a process to position the device 108 such that each pin 104 of the device 108 corresponds to the tip of the corresponding tapered wall portion to form small holes therein by the device 108.

The fifth method for producing a filter will be explained. The closure device 101 used in the fifth method comprises the opening closure device 105 shown in Figs. 27A and 27B and a hole formation device 110 shown in the plan view of Fig. 31. Figs. 32A and 32B show the device 110 in detail.

Fig. 32A shows a plan view of the hole formation device 110 in which an end wall 113 is omitted. As can be understood from Fig. 32A, the device 110 has predetermined numbers of drill members 112. As can be understood from Fig. 32B showing one of the drill members 112, each member 112 has a gear 113 and a drill 114 which extends from the central portion of the gear 113 in a direction perpendicular to the end wall surface of the gear 113.

As shown in Fig. 32A, each drill member 112 engag s with corresponding intermediate gears 115. Two adjacent drill members 112 are connected via one intermediate gear

115. A certain drill member 112 engages with a drive gear 116. The gear 116 is rotated by a suitable drive means such as an electric motor. When the drive gear 116 is rotated, the drill member 112 engaging with the drive gear 116 is rotated, and then the rotation of the member 112 is transmitted to all remaining drill members 112 via the intermediate gears 116. As a result, each drill member 112 is rotated about its longitudinal axis.

Note that the drills 114 of the drill members 112 are projected from the end wall 113 of the hole forming device 110. The drills 114 are arranged in the same pattern as that regarding the pins 104 of the device 106 shown in Figs. 28A and 28B.

According to the fifth method, similar to the third method, the opening closure device 105 shown in Fig. 27A is pressed onto one of the end faces of the substrate 100 to completely close the end opening of each exhaust gas passages 50 by a tapered wall portion. Next, the drive gear 116 of the hole formation device 110 is rotated, and the device 110 is pressed onto one end face of the substrate 100 such that the drill 114 of each drill member 112 pierces the tip of the corresponding tapered wall portion which completely closes the end opening of the corresponding exhaust gas passage 51. As a result, a small hole 56 is formed in the tip of each tapered wall portion by the corresponding rotating drill 114.

Regarding the other end face of the substrate 100, the similar processes are performed. That is, similar to the third method, the opening closure device 105 is pressed onto the other end face of the substrate 100 to completely close the end opening of each exhaust gas passage 51 by the corresponding tapered wall portion. Next, the drive gear 116 of the hole formation device 110 is rotated, and the device 110 is pressed onto the other end face of the substrate 100 such that the drill 114 of each drill member 112 pierces the tip of the corresponding tapered wall portion which completely

closes the end opening of the corresponding exhaust gas passage 50. As a result, a small hole 55 is formed in the tip of each tapered wall portion by the corresponding rotating drill 114.

According to the fifth method, the small holes are formed in the tips of the tapered wall portions by the rotating drills 114. Therefore, the tapered wall portions are hardly subject to damage when the small holes are formed, comparing with the case that the holes are formed in the tips of the tapered wall portions simply by pins.

The sixth method for producing a filter will be explained. The closure device 101 used in the sixth method comprises the opening closure device 105 shown in Fig. 27A and a hole formation device 117 shown in Fig. 33A. In Fig. 33A, the end wall 118 of the device 117 shown in Fig. 33B is omitted.

As shown in Fig. 33A, the device 117 has predetermined numbers of drill members 119. As shown in Fig. 33B, each drill member 119 has a ball 120 and a drill 121 which extends from the ball 120.

As shown in Fig. 33B, a plurality of annular grooves 123 are formed in a disc body 122 of the device 117. The center of each groove 123 corresponds to the center of the body 122. The body 122 is rotated by a suitable means such as an electric motor about an axis A shown in Fig. 33B.

The ball 120 of each drill member 119 is housed in the corresponding groove 123 such that the ball 120 is in contact with the side wall surface defining the groove 123. The drills 121 of the drill members 119 project from the end wall 118 of the device 117. The drills 121 are arranged in the same pattern as that of the pins 104 of the device 106 shown in Fig. 28A.

When the body 122 is rotated, the ball 120 of each drill member 119 is rotated by the side wall surface of the corresponding groove 123 of the body 122. As a

result, the drill 121 of each drill member 119 is rotated about its longitudinal axis.

Note that each drill member 119 may have a bevel gear in place of the ball 120. In this case, a bevel gear is provided on the side wall surface of each groove 123. The bevel gear of each drill member 119 engages with the bevel gear of the side wall surface of the corresponding groove 123. When the body 122 is rotated, the bevel gear of each drill member 119 is rotated by the body 122.

According to the sixth method, similar to the third method, the opening closure device 105 shown in Fig. 27A is pressed onto one of the end faces of the substrate 100 to completely close the end openings of the exhaust gas passages 51 by the tapered wall portions. Next, the body 122 of the device 117 is rotated, and the device 117 is pressed onto one end face of the substrate 100 such that the drill 121 of each drill member 119 pierces the tip of the corresponding tapered wall portion which completely closes the end opening of the corresponding exhaust gas passage 51. As a result, a small hole 56 is formed in the tip of each tapered wall portion by the corresponding rotating drill 121.

Regarding the other end face of the substrate 100, the similar processes are performed. That is, similar to the third method, the opening closure device 105 is pressed onto the other end face of the substrate 100 to completely close the end openings of the exhaust gas passages 50 by the tapered wall portions. Next, the body 122 of the device 117 is rotated, and the device 117 is pressed onto the other end face of the substrate 100 such that the drill 121 of each drill member 119 pierces the tip of the corresponding tapered wall portion which completely closes the end opening of the corresponding exhaust gas passage 50. As a result, a small hole 55 is formed in the tip of each tapered wall portion by the corresponding rotating drill 121.

The seventh method for producing a filter will be explained. The closure device 101 used in the seventh method comprises the opening closure device 105 shown in Fig. 27A and a hole formation device 124 shown in Fig. 34B.

The device 124 is a disc shape having generally the same diameter as that of the device 105. Further, the device 124 has a body 125 and a shaving layer 126 attached to the body 125. The layer 126 is formed of abrasive for shaving the tips of the tapered wall portions of the substrate 100. Furthermore, the device 124 is rotated about an axis B by a suitable means such as an electric motor.

According to the seventh method, similar to the third method, as shown in Fig. 34A, the device 105 shown in Fig. 27A is pressed onto one of the end faces of the substrate 100 to completely close the end openings of the exhaust gas passages 51 by the tapered wall portions. Next, the device 124 is rotated about the axis B, and is pressed onto one end face of the substrate 100. As a result, the shaving layer 126 of the device 124 is pressed onto the tips of the tapered wall portions of th substrate 100. The tips of the tapered wall portions are shaved by the shaving layer 126. As a result, a small hole 56 is formed in the tip of each tapered wall portion.

Regarding the other end face of the substrate 100, the similar processes are performed. That is, similar to the third method, the device 105 is pressed onto the other end face of the substrate 100 to completely close the end openings of the exhaust gas passages 50 by the tapered wall portions. Next, the device 124 is rotated about the axis B, and pressed onto the other end face of the substrate 100. As a result, a small hole 55 is formed in the tip of each tapered wall portion.

The above explained methods have an advantage that small holes 55,56 each having a desired opening area,

i.e., the generally same opening area can be obtained. The opening area of each small hole 55,56 influences the pressure loss and the particulate collection ratio of the filter 22. That is, the pressure loss and the particulate collection ratio of the filter 22 are changed by changing the opening area of the holes 55,56. According to the above explained methods, holes 55,56 each having a desired opening area can be obtained, and thus the filter 22 having the desired pressure loss and the desired particulate collection ratio is obtained.

While the invention has been described by reference to specific embodiments chosen for purposes of illustration, it should be apparent that numerous modifications could be made thereto by those skilled in the art without departing from the basic concept and scope of the invention.

CLAIMS

1. An exhaust gas purification device comprising a substrate used for purifying components contained in an exhaust gas discharged from an engine, the substrate having partitions which define passages and are formed of porous material having fine pores each having a predetermined average size, the end portions of the adjacent partitions defining each of part of the passages of the substrate being partially connected to each other such that the end portions are tapered toward the outside of the substrate, the tapered end portions partially closing the end opening of the corresponding passage and forming a small hole defined by the tips thereof, and the size of each small hole being smaller than the cross sectional area of the corresponding passage and larger than the sizes of the fine pores of the partitions.

2. An exhaust gas purification device as set forth in claim 1, wherein the end portions of the adjacent partitions defining each of part of the passages of the substrate are partially connected to each other at their upstream ends such that the end portions are tapered toward the outside of the substrate, and the end portions of the adjacent partitions defining each of remaining passages of the substrate are partially connected to each other at their downstream ends such that the end portions are tapered toward the outside of the substrate.

3. An exhaust gas purification device as set forth in claim 2, wherein the tapered end portions and the remaining partitions carry oxidation material for oxidizing the particulates, and the amount of the oxidation material carried by each upstream tapered end portion per unit volume is larger than that carried by each downstream tapered end portion per unit volume.

4. An exhaust gas purification device as set forth in claim 1, wherein the end portions of the adjacent partitions defining each of part of the passages of the substrate are partially connected to each other at their

upstream ends such that the end portions are tapered toward the outside of th substrate, and the end portions of the adjacent partitions defining each of remaining passages of the substrate are connected to each other at their downstream ends such that the end portions are tapered toward the outside of the substrate and the downstream end opening of the passage is completely closed.

5. An exhaust gas purification device as set forth in claim 1, wherein the end portions of the adjacent partitions defining each of part of the passages of the substrate are partially connected to each other at their downstream ends such that the end portions are tapered toward the outside of the substrate, and the end portions of the adjacent partitions defining each of remaining passages of the substrate are connected to each other at their upstream ends such that the end portions are tapered toward the outside of the substrate and the upstream end opening of the passage is completely closed.

6. An exhaust gas purification device as set forth in claim 1, wherein the substrate is used as a particulate filter arranged in an exhaust gas passage of an engine for collecting particulates contained in an exhaust gas discharged from an engine.

7. An exhaust gas purification device as set forth in claim 6, wherein the tapered end portions carry oxidation material for oxidizing the particulates.

8. An exhaust gas purification device as set forth in claim 7, wherein the amount of the oxidation material carried by each tapered end portion at its upstream surface per unit are is larger than that at its downstream surface per unit area.

9. An exhaust gas purification device as set forth in claim 7, wherein a process for increasing the temperature of the filter is performed.

10. An exhaust gas purification device as set forth in claim 7, wherein the filter carries a NOx carrying

agent to take in and carry the NOx therein when excessive oxygen exists therearound, and to discharge the carried NOx therefrom when the concentration of the oxygen decreases.

11. An exhaust gas purification device as set forth in claim 7, wherein the filter carries a precious metal catalyst.

12. An exhaust gas purification device as set forth in claim 11, wherein the oxidation material is an active oxygen production agent to take in and carry the oxygen when excessive oxygen exists therearound, and to discharge the carried oxygen therefrom in the form of active oxygen when the concentration of the oxygen decreases, and the active oxygen production agent discharges the active oxygen therefrom when the particulates adhere to the filter to oxidize the particulate adhering to the filter by the active oxygen.

13. An exhaust gas purification device as set forth in claim 12, wherein the active oxygen production agent comprises one of an alkali metal, an alkali earth metal, a rare earth and a transition metal.

14. An exhaust gas purification device as set forth in claim 12, wherein the active oxygen production agent comprises one of an alkali metal and an alkali earth metal having an ionization tendency higher than that of calcium.

15. An exhaust gas purification device as set forth in claim 12, wherein the air fuel ratio of at least part of the exhaust gas flowing into the filter is temporarily made rich to oxidize the particulates adhering to the filter.

16. An exhaust gas purification device as set forth in claim 6, wherein an oxidation means for oxidizing components contained in the exhaust gas is arranged in the exhaust gas passage of the engine upstream of the filter.

17. An exhaust gas purification device as set forth

in claim 16, wherein the oxidation means is an oxidation catalyst.

18. An exhaust gas purification device as set forth in claim 16, wherein the oxidation means is a NOx catalyst to carry the NOx when the lean exhaust gas flows thereinto and to reduce the carried NOx when the rich exhaust gas flows thereinto.

19. An exhaust gas purification device as set forth in claim 6, wherein the size of each small hole of the filter at the low temperature region of the filter is larger than that at the high temperature region of the filter.

20. An exhaust gas purification device as set forth in claim 19, wherein the low temperature region is the peripheral region of the filter, and the high temperature region is the central region of the filter.

21. An exhaust gas purification device as set forth in claim 19, wherein the cross sectional area of each passage of the filter at the low temperature region of the filter is larger than that at the high temperature region of the filter.

22. An exhaust gas purification device as set forth in claim 6, wherein the cross sectional area of each passage of the filter at the low temperature region of the filter is larger than that at the high temperature region of the filter.

23. An exhaust gas purification device as set forth in claim 22, wherein the low temperature region is the peripheral region of the filter, and the high temperature region is the central region of the filter.

24. An exhaust gas purification device as set forth in claim 22, wherein the size of each small hole of the filter at the low temperature region of the filter is larger than that at the high temperature region of the filter.

25. An exhaust gas purification device as set forth in claim 6, wherein an exhaust gas purification means for

purifying components contained in the exhaust gas is arranged in the exhaust gas passage of the engine downstream of the filter.

26. An exhaust gas purification device as set forth in claim 25, wherein the exhaust gas purification means is a NOx catalyst to carry the NOx when the lean exhaust gas flows thereinto, and to reduce the carried NOx when at least the generally stoichiometric exhaust gas flows thereinto.

27. An exhaust gas purification device as set forth in claim 25, wherein the exhaust gas purification means is an additional particulate filter which can oxidize the particulates contained in the exhaust gas.

28. An exhaust gas purification device as set forth in claim 25, wherein the filter is arranged at least near the exhaust manifold.

29. An exhaust gas purification device as set forth in claim 25, wherein the device further comprises a bypass passage which extends from the engine exhaust gas passage between the filter and the exhaust gas purification means to the exhaust gas passage of the engine downstream of the exhaust gas purification means to bypass the exhaust gas purification means, and a switch valve for switching the flow of the exhaust gas into the exhaust gas purification means and into the bypass passage, the filter carries a SOx carrying agent to carry the SOx when the lean exhaust gas flows thereinto, and to release the carried SOx when at least the generally stoichiometric exhaust gas flows thereinto and the temperature of the SOx carrying agent has a temperature higher than a SOx release temperature, the switch valve is positioned such that the exhaust gas flows into the exhaust gas purification means when the SOx is not released from the SOx carrying agent, and is positioned such that the exhaust gas flows into the bypass passage when the SOx is released from the SOx carrying agent.

30. An exhaust gas purification device as set forth in claim 29, wherein a catalyst for oxidizing the components contained in the exhaust gas is arranged in the bypass passage.

31. An exhaust gas purification device as set forth in claim 1, wherein the substrate is arranged in an exhaust gas passage of an engine, the substrate carrying a hydrocarbon collection agent for collecting unburned hydrocarbon contained in an exhaust gas discharged from an engine, and a hydrocarbon purification catalyst for purifying unburned hydrocarbon, the hydrocarbon collection agent collects unburned hydrocarbon when the agent has a temperature lower than a hydrocarbon release temperature, and releases the collected unburned hydrocarbon therefrom when the agent has a temperature higher than the hydrocarbon release temperature, the hydrocarbon purification catalyst purifies unburned hydrocarbon when the catalyst has a temperature higher than a hydrocarbon purification temperature, the hydrocarbon release temperature is set such that the unburned hydrocarbon is released from the hydrocarbon collection agent when the hydrocarbon purification catalyst has a temperature lower than the hydrocarbon purification temperature.

32. A method for producing a substrate used for purifying components contained in an exhaust gas discharged from an engine, the substrate having a plurality of exhaust gas passages defined by partitions formed of porous material, the end portions of the partitions defining each of part of the exhaust gas passages being partially connected to each other at one end of the exhaust gas passage such that the end portions are tapered toward the outside of the substrate and define a small hole by the tips thereof, the end portions of the partitions defining each of the remaining exhaust gas passages being partially connected to each other at the other end of the exhaust gas passage such that the

end portions are tapered toward the outside of the substrate and define a small hole by the tips thereof, wherein the method comprises a step of gathering and connecting the end portions of the partitions defining each exhaust gas passage to be closed at its end opening, and a step of forming a small hole defined by the tips of the end portions defining each exhaust gas passage to be closed at its end opening, each small hole having a size smaller than the area of the end opening of the corresponding exhaust gas passage and larger than the average sizes of the fine pores of the partitions.

33. A method as set forth in claim 32, wherein the gathering and connecting step and the small hole forming step are simultaneously performed.

34. A method as set forth in claim 33, wherein the gathering and connecting step and the small hole forming step are simultaneously performed by pressing a device having a plurality of projections and pins arranged between the projections onto the end face of the substrate.

35. A method as set forth in claim 32, wherein first, the gathering and connecting step is performed, and then the small hole forming step is performed.

36. A method as set forth in claim 35, wherein in the small hole forming step, the tips of the end portions connected to each other are shaved to form the small hole.

ABSTRACT

There is provided an exhaust gas purification device (22) comprising a substrate used for purifying components contained in an exhaust gas discharged from an engine. The substrate has partitions (54) which define passages (50,51) and are formed of porous material having fine pores each having a predetermined average size. The end portions of the adjacent partitions (54) defining each of part of the passages (50,51) of the substrate are partially connected to each other such that the end portions (52,53) are tapered toward the outside of the substrate. The tapered end portions partially close the end opening of the corresponding passage and form a small hole (55,56) defined by the tips thereof. The size of each small hole (55,56) is smaller than the cross sectional area of the corresponding passage (50) and larger than the sizes of the fine pores of the partitions (54).

Fig.1A

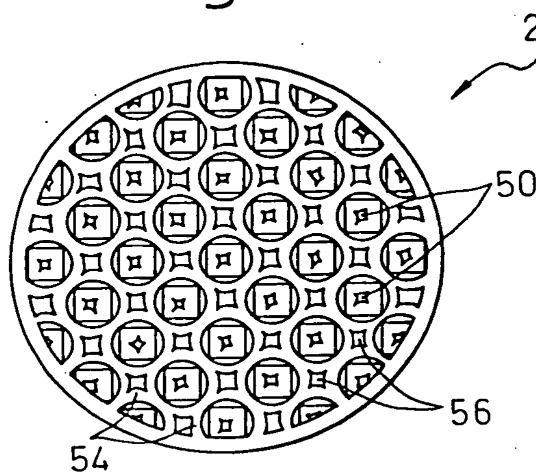

22
50
56
54

Fig.1B

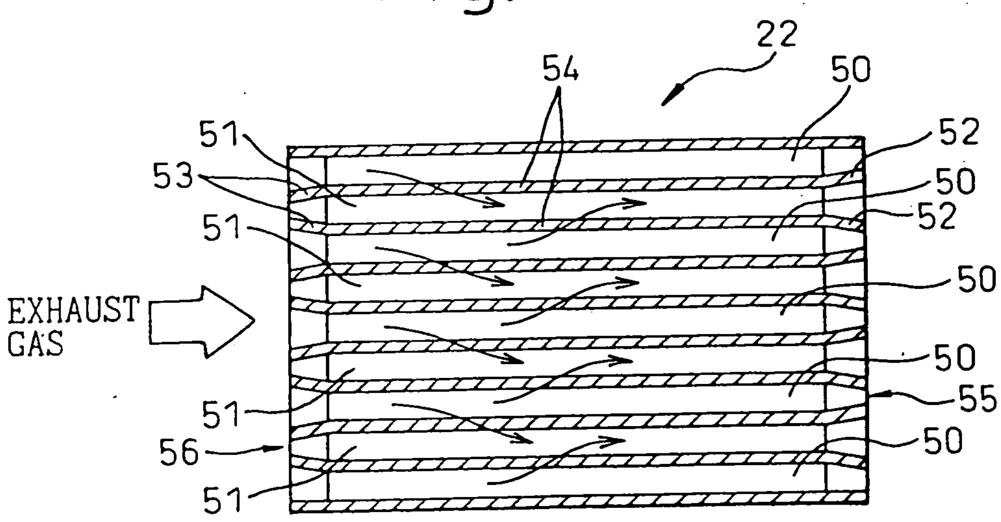

22
54
50
51
52
53
50
51
52
50
EXHAUST GAS
50
51
55
56
50
51

Fig.2A

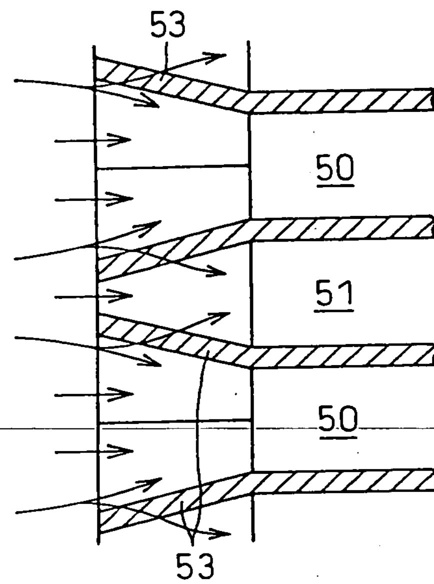


Fig.2B

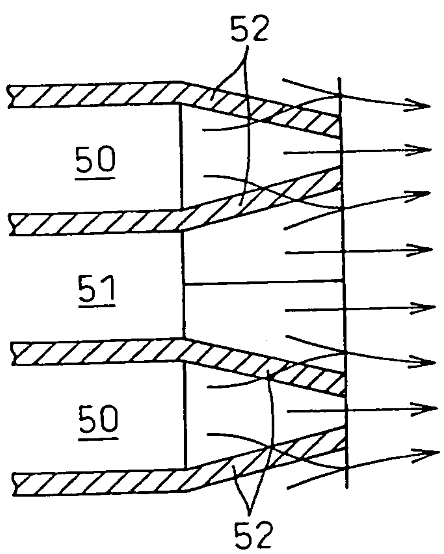


Fig.3A

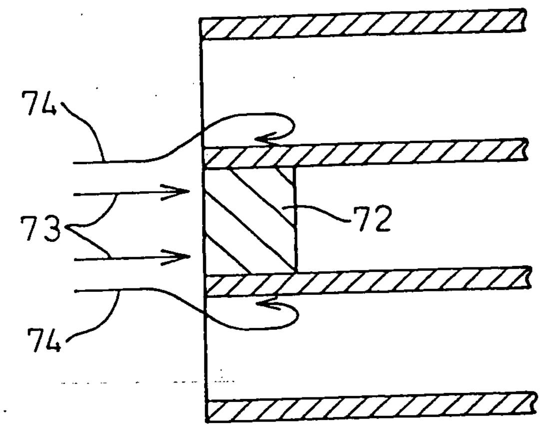


Fig.3B

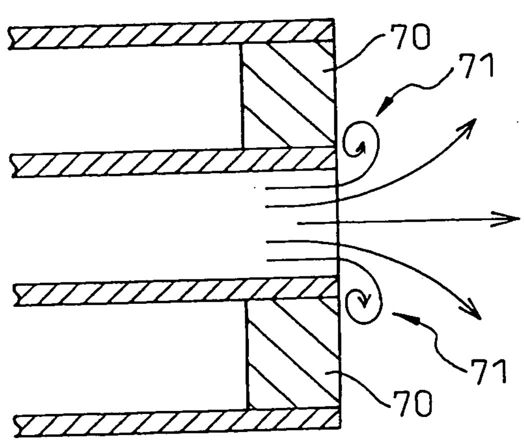


Fig.4A

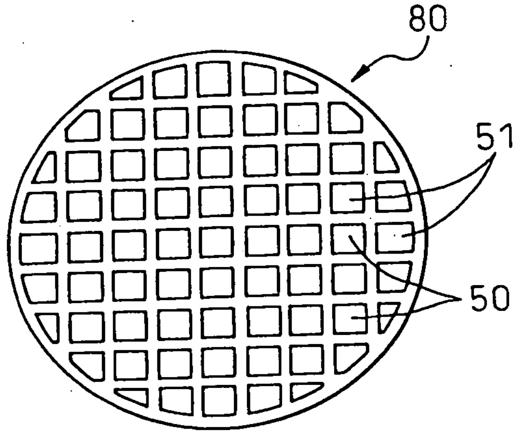


Fig.4B

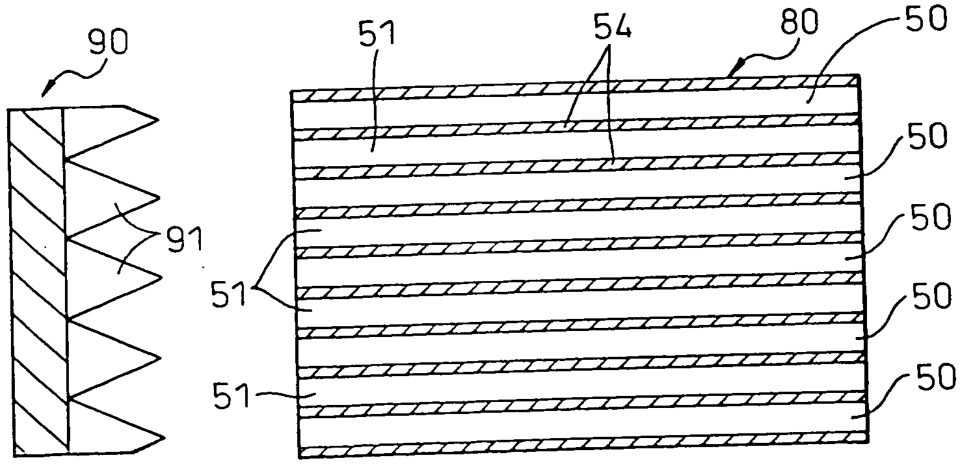


Fig.5A

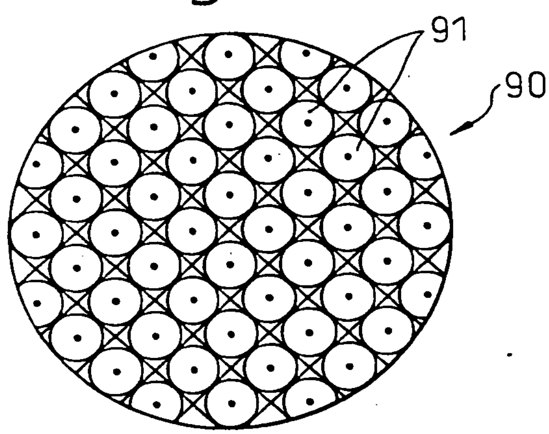


Fig.5B

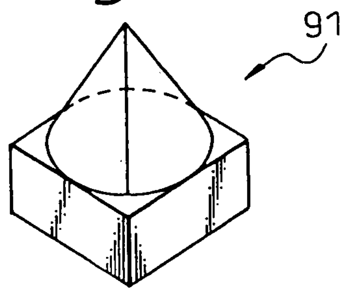


Fig.6A

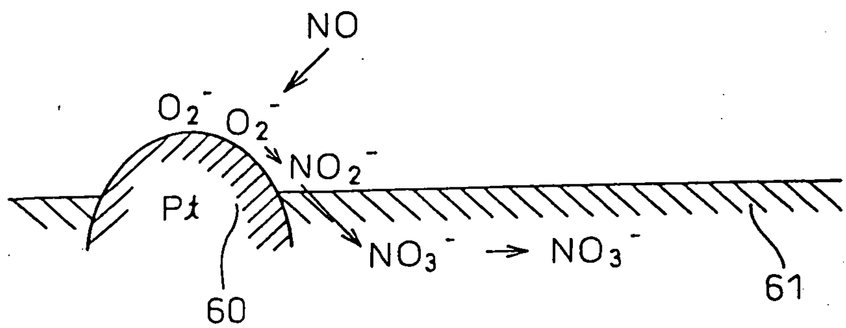


Fig.6B

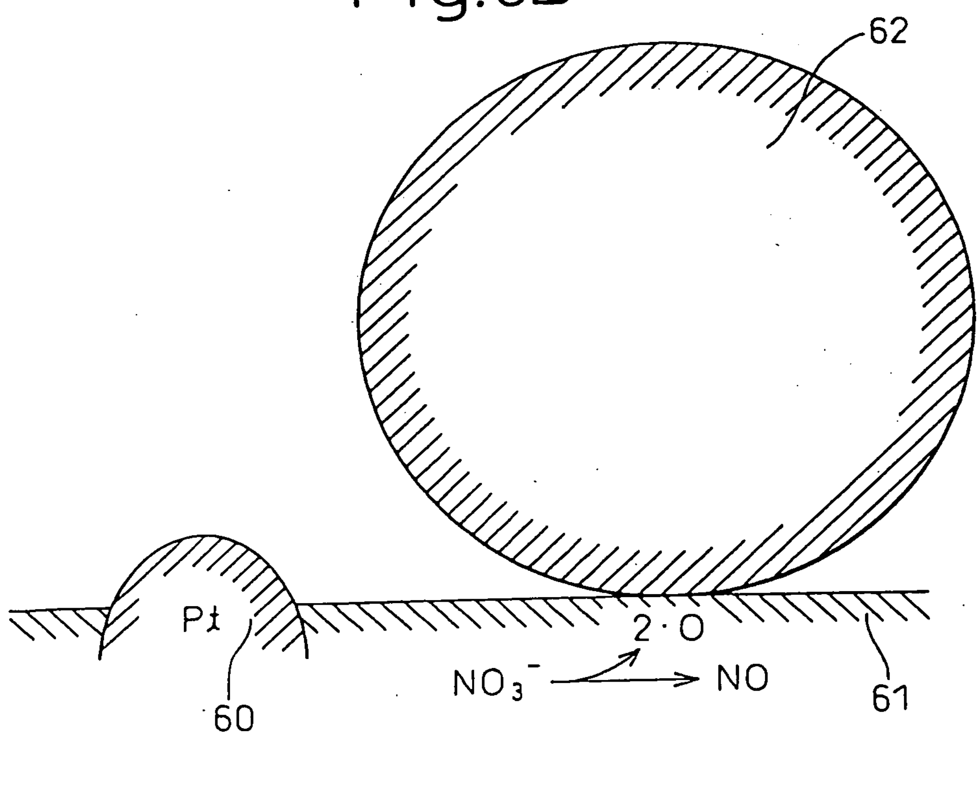


Fig.7A

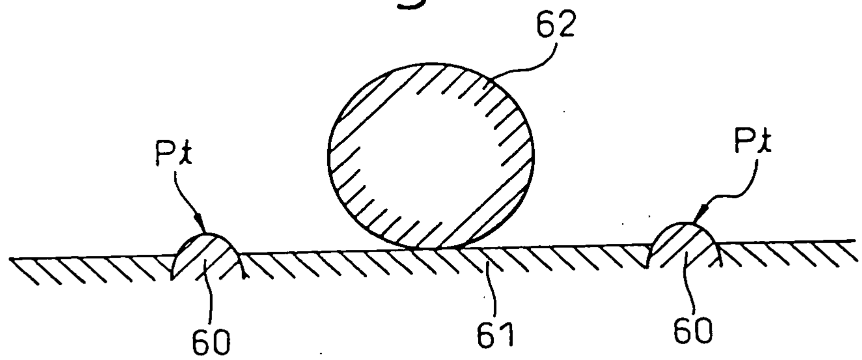


Fig.7B

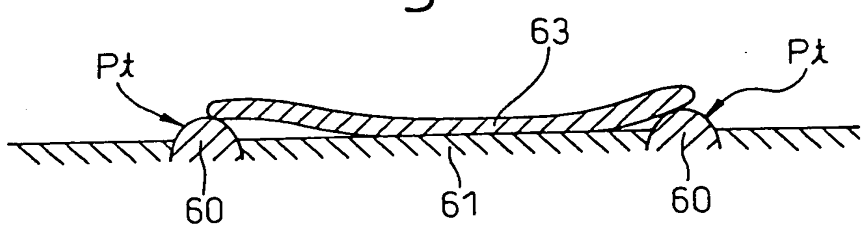


Fig.7C

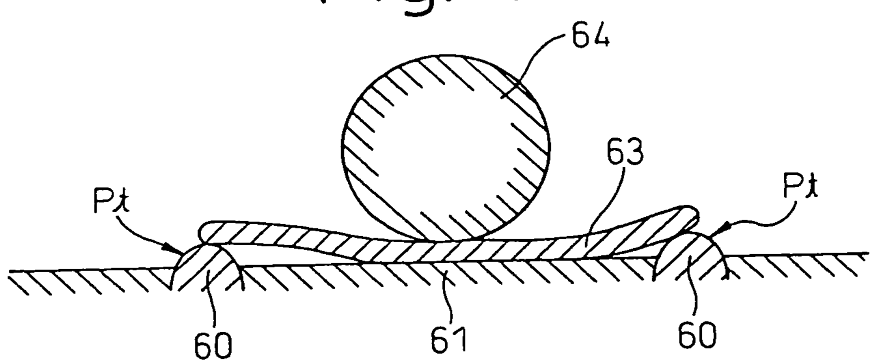
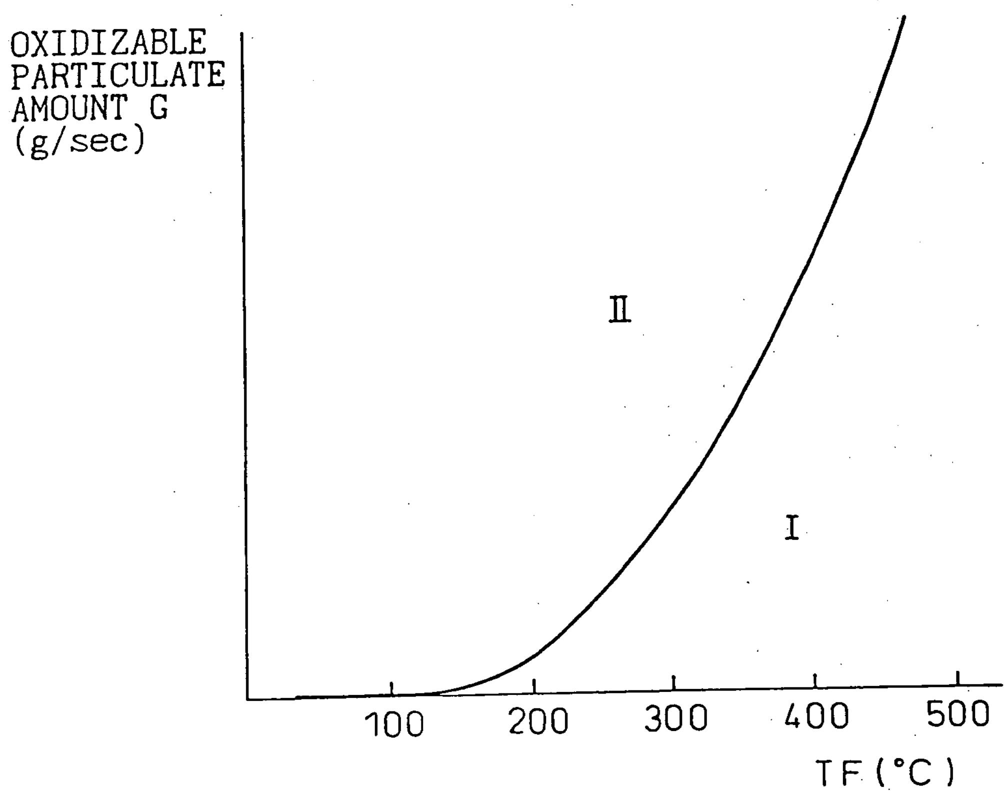


Fig.8


OXIDIZABLE
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TF (°C)

Fig.9A

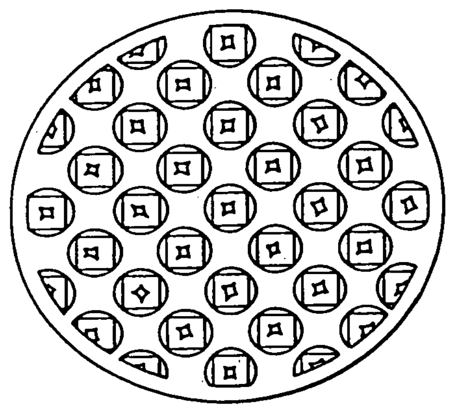


Fig.9B

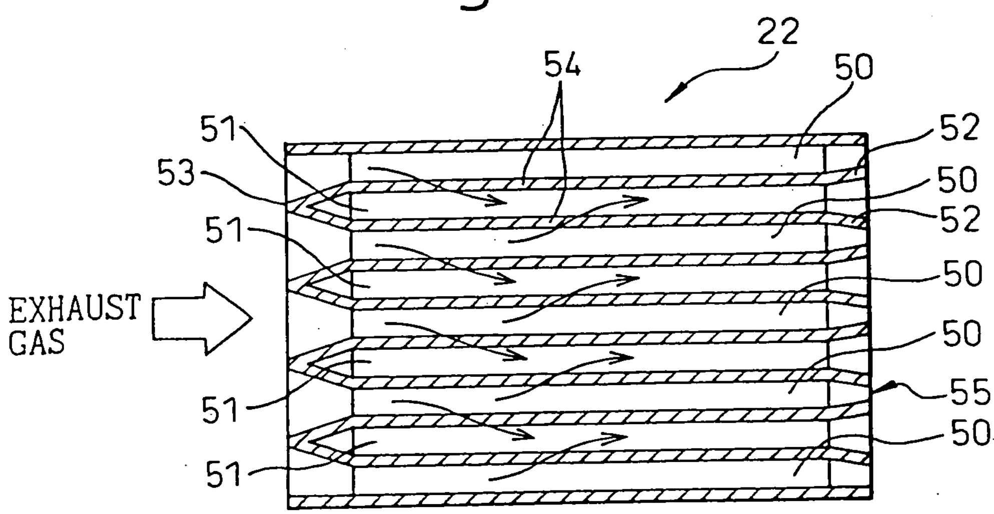


Fig.10A

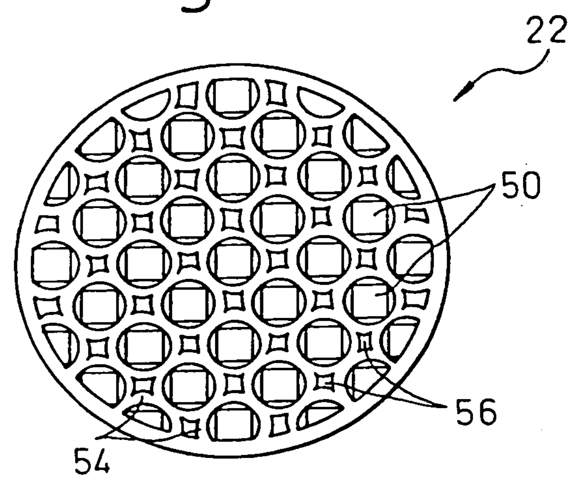


Fig.10B

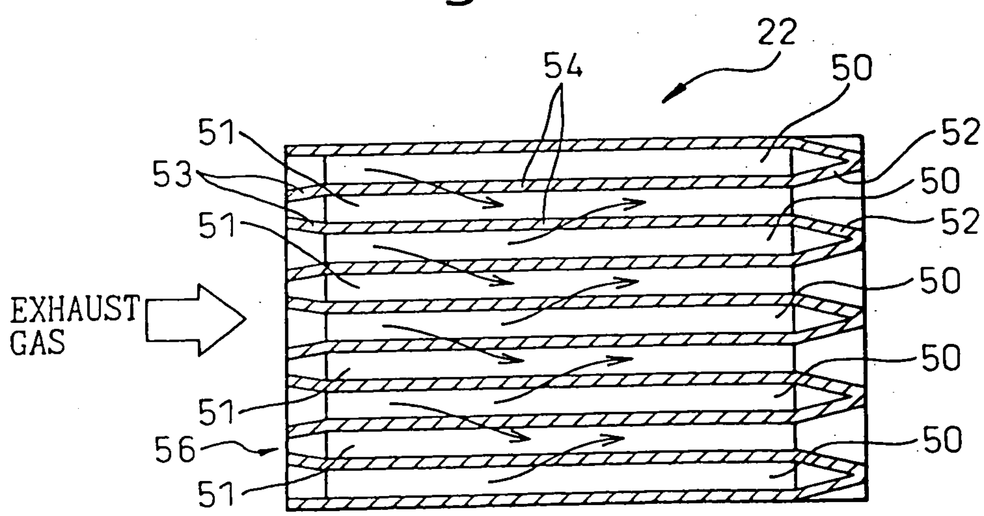
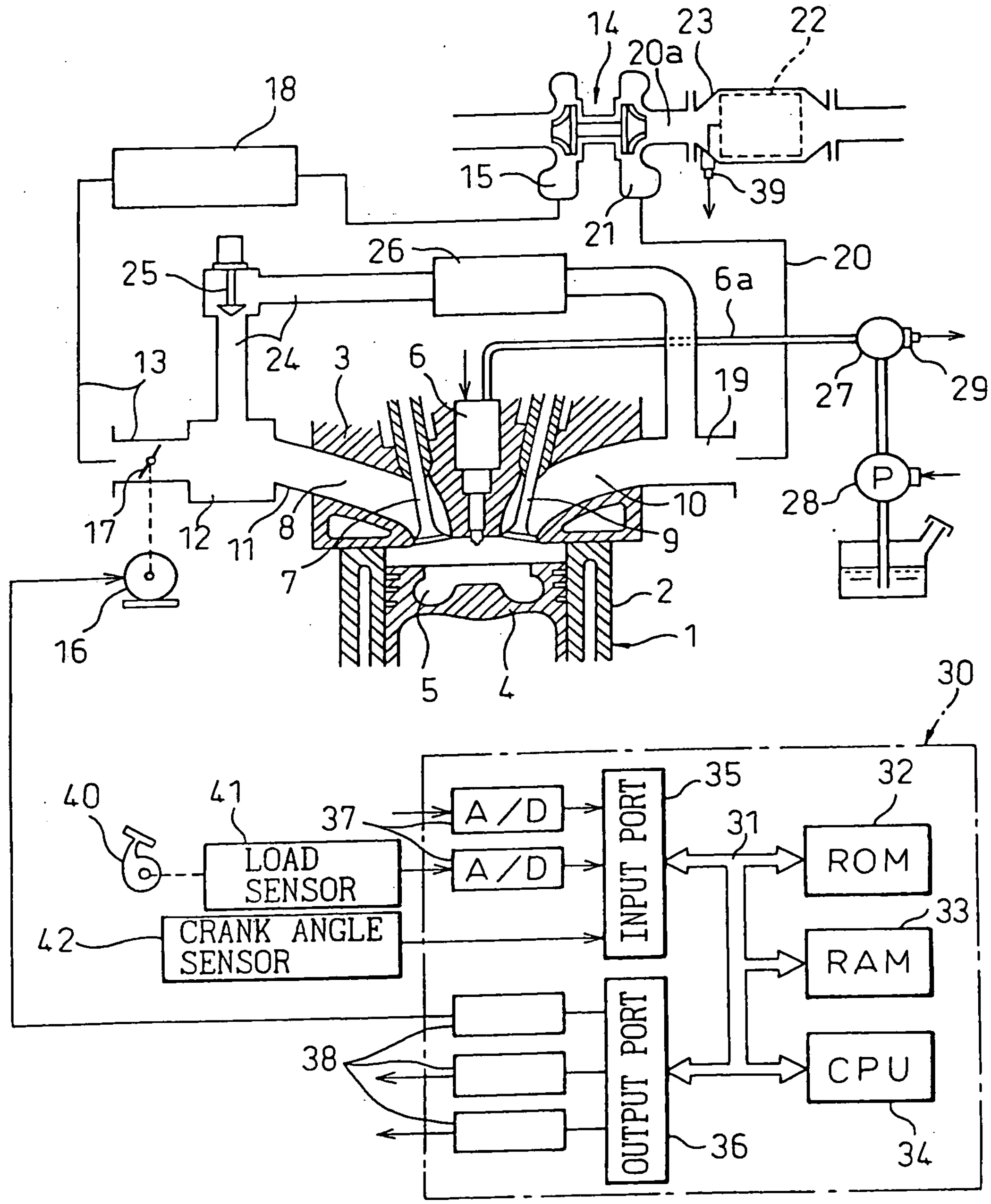


Fig.11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INPUT PORT
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CRANK ANGLE SENSOR
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OUTPUT PORT
CPU
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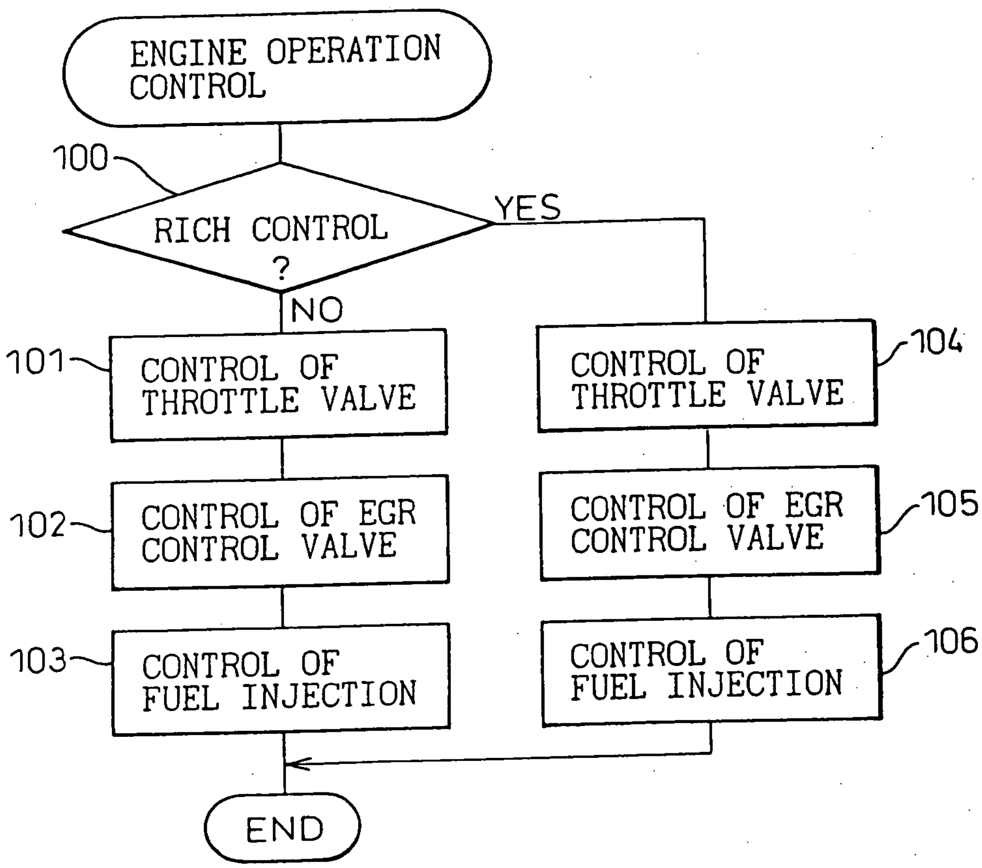
Fig.12


ENGINE OPERATION CONTROL
100
RICH CONTROL ?
YES
NO
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CONTROL OF THROTTLE VALVE
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CONTROL OF EGR CONTROL VALVE
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CONTROL OF FUEL INJECTION
104
CONTROL OF THROTTLE VALVE
105
CONTROL OF EGR CONTROL VALVE
106
CONTROL OF FUEL INJECTION
END

Fig.13

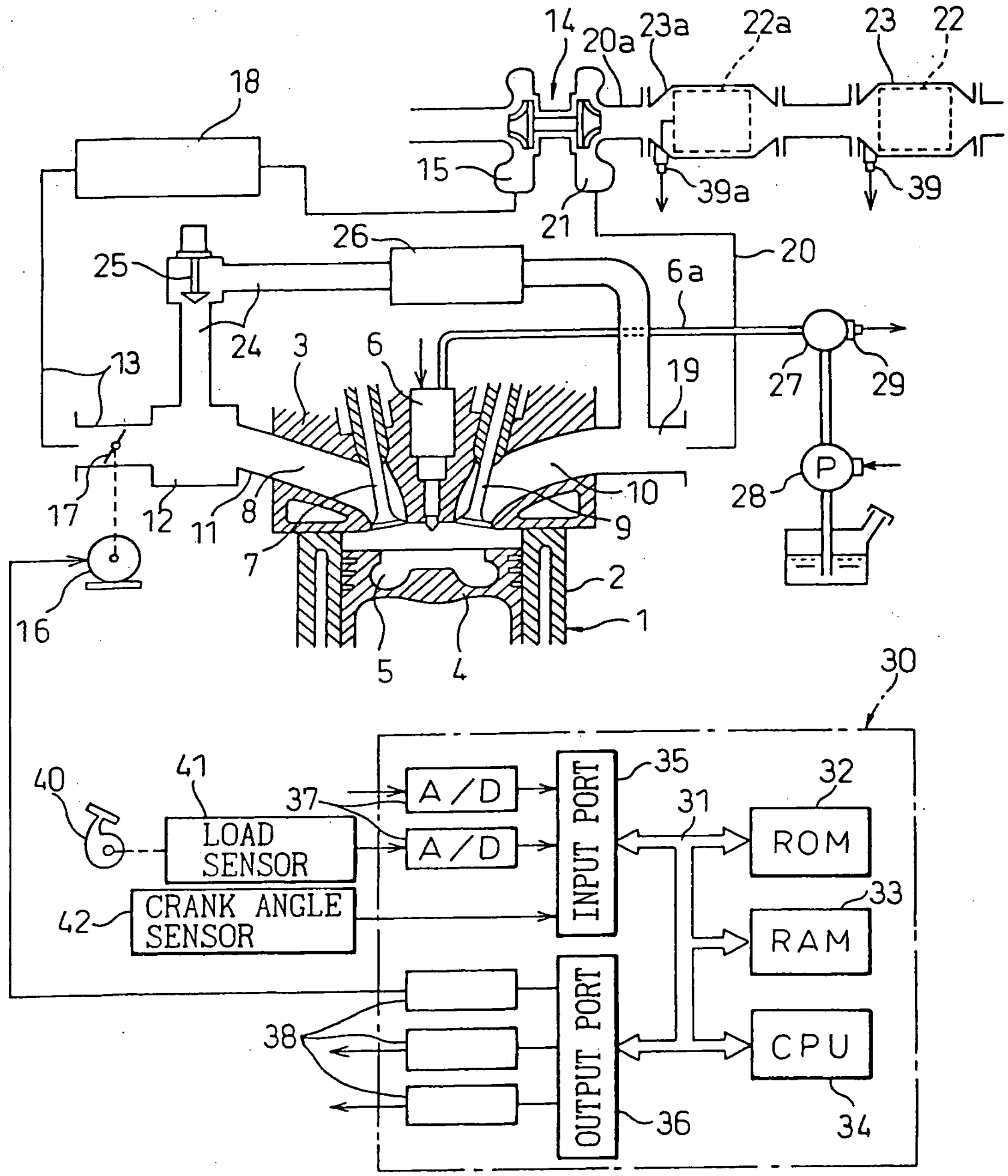

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Fig.14A

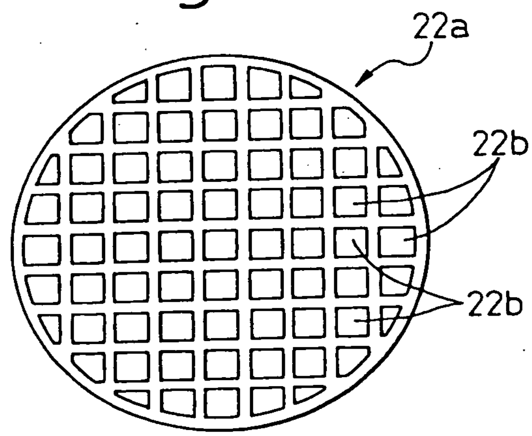

Fig.14B

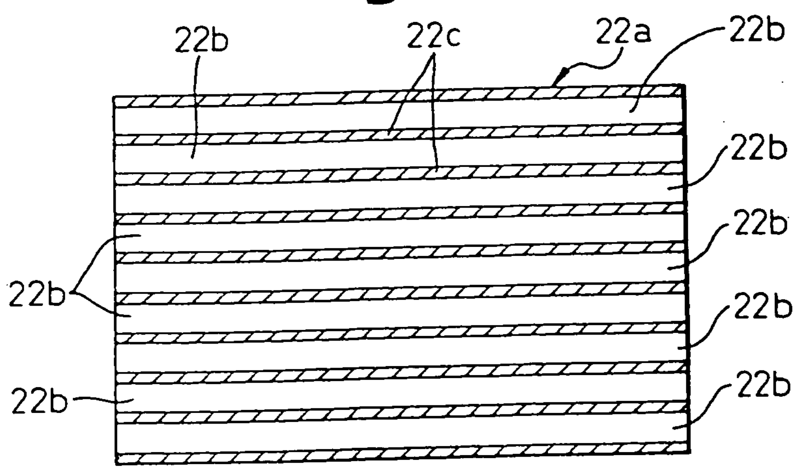

Fig.15A

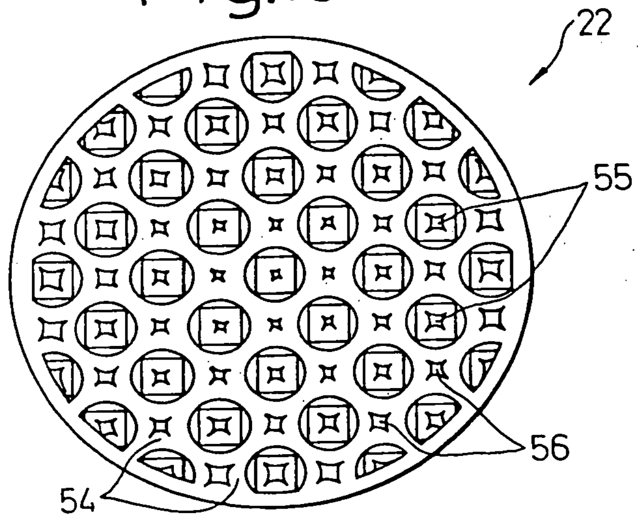

Fig.15B

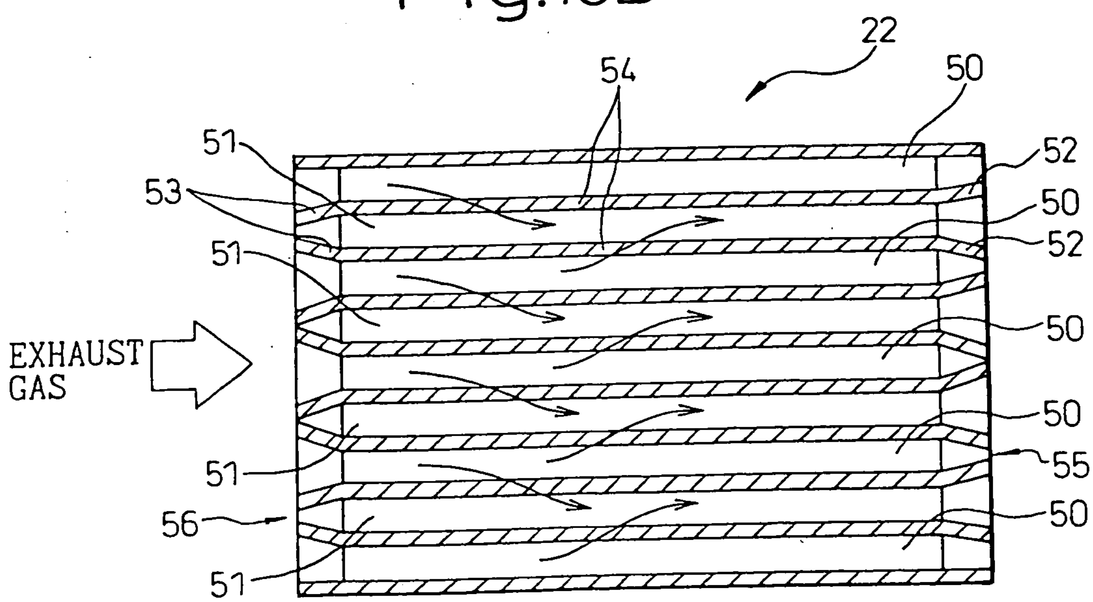

Fig.16A

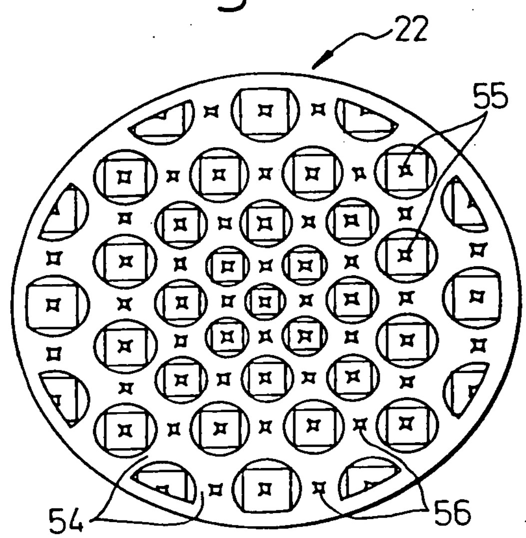

Fig.16B

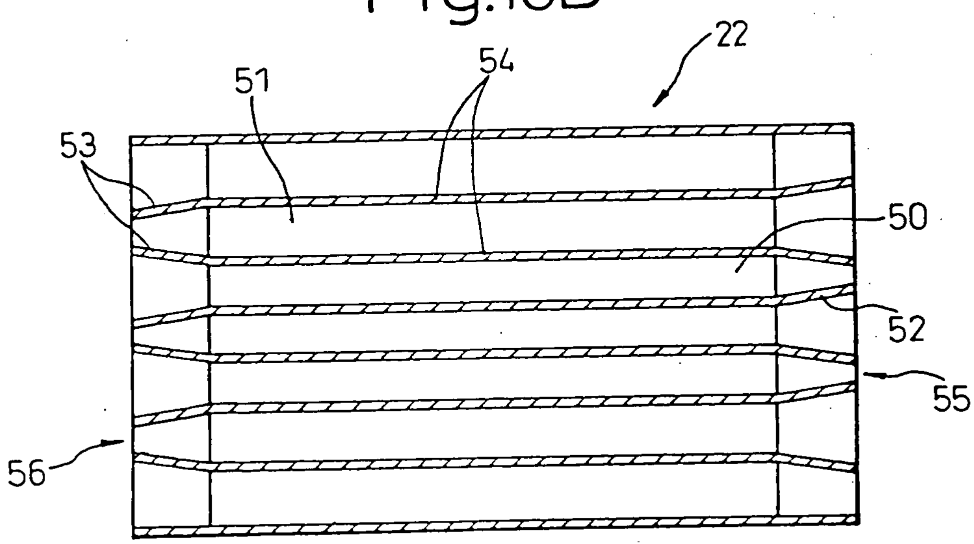

Fig.17

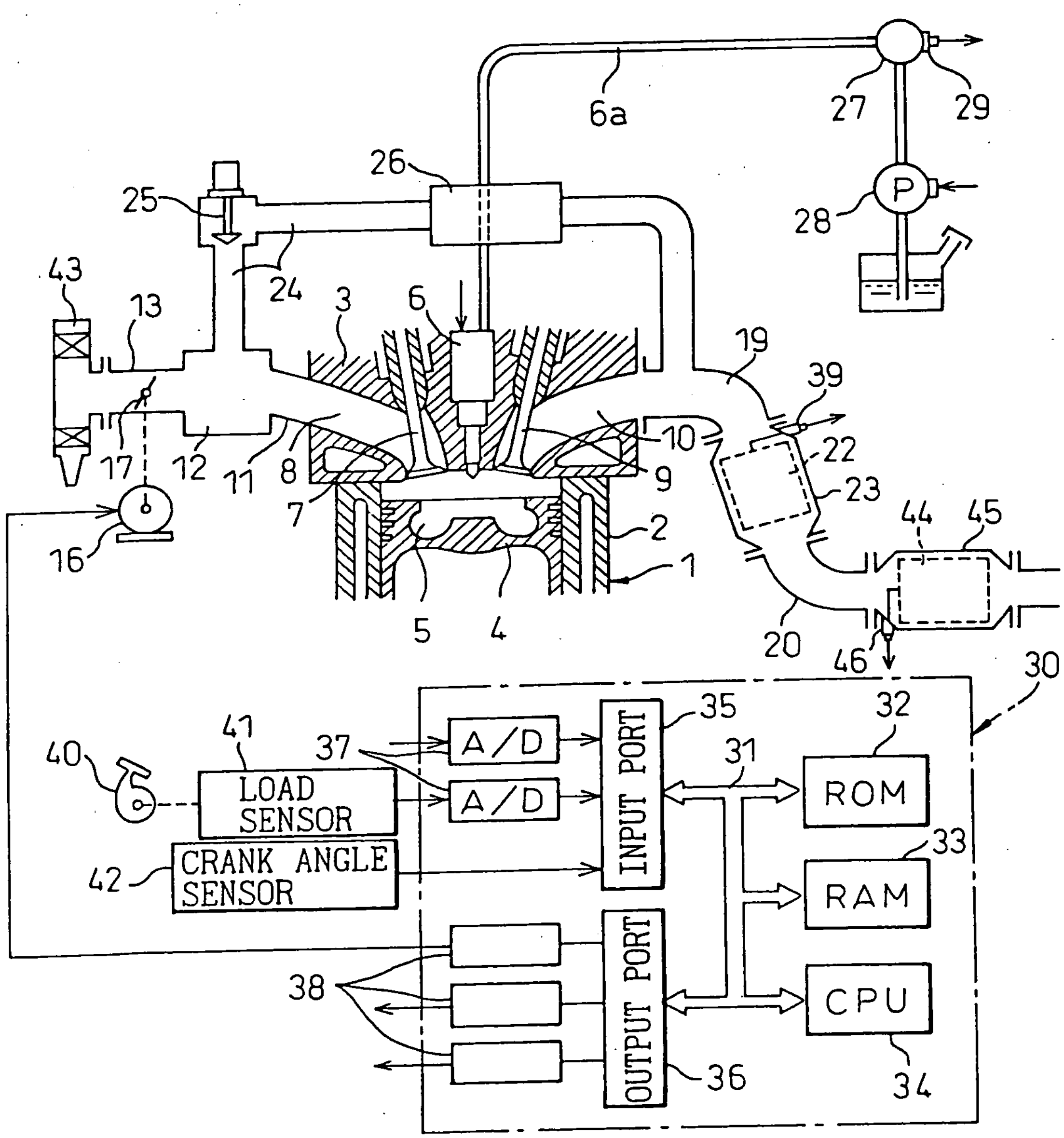

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Fig.18A

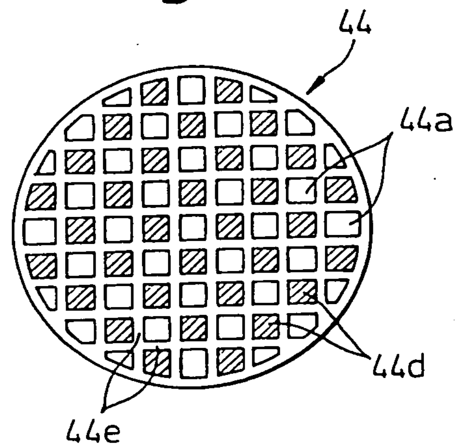

Fig.18B

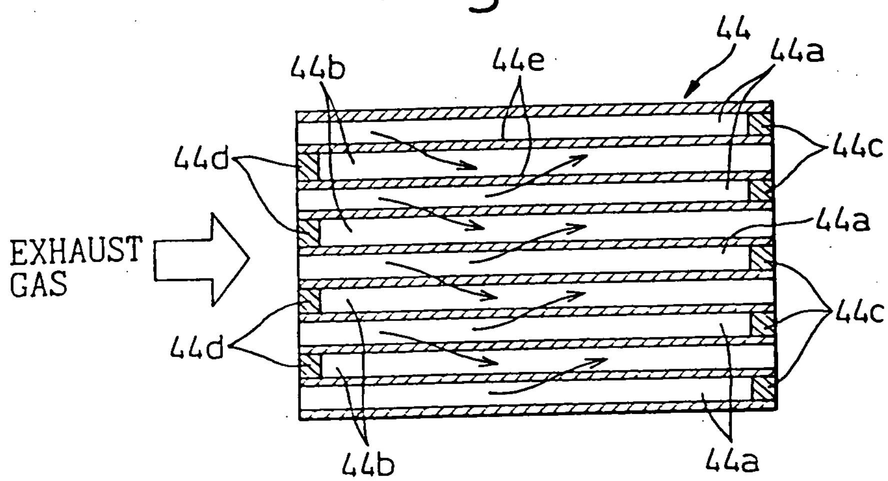

Fig.19A

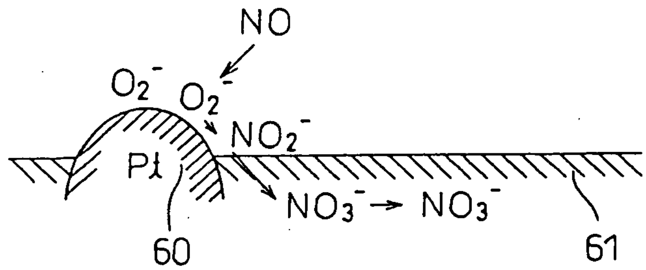

Fig.19B

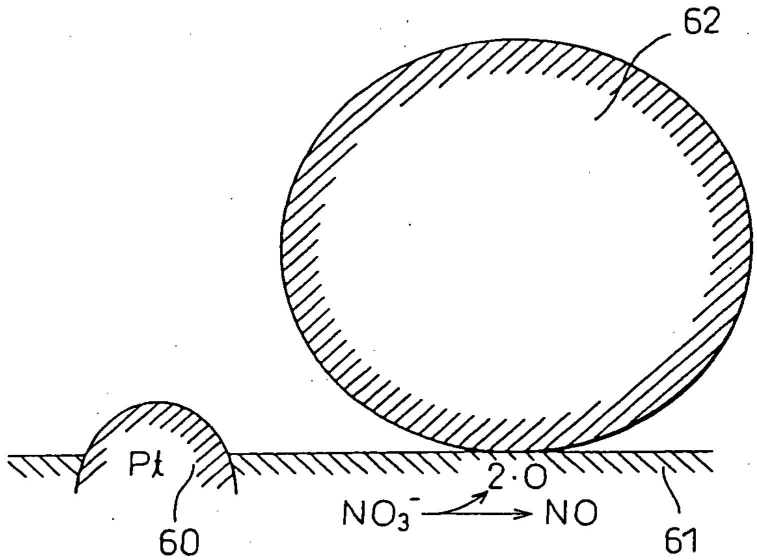

Fig.19C

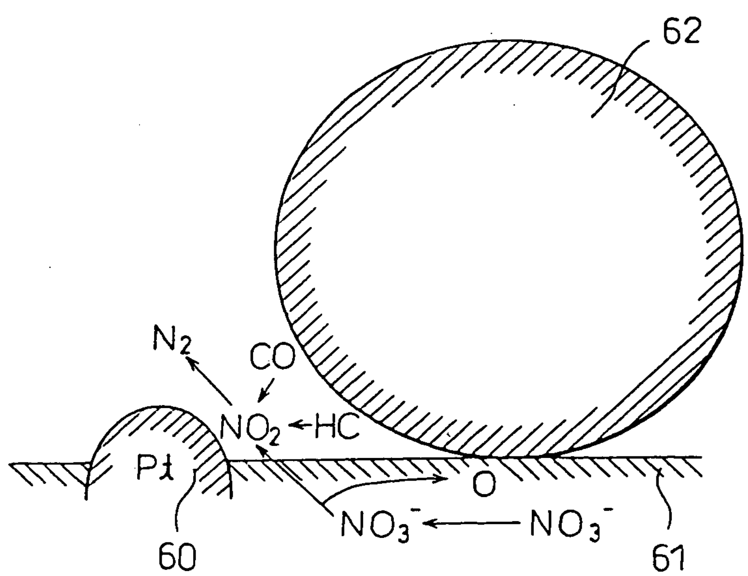

Fig.20

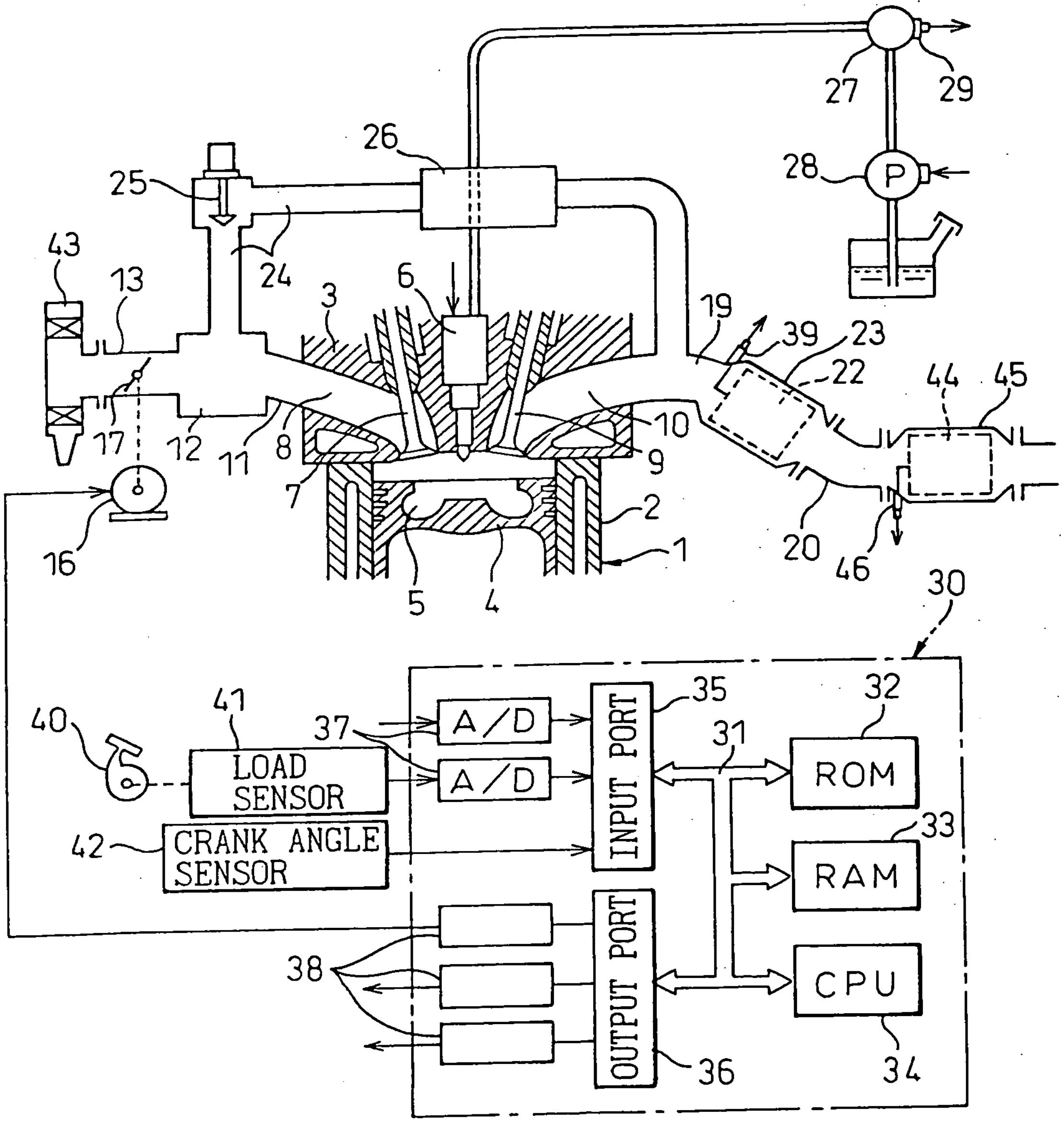

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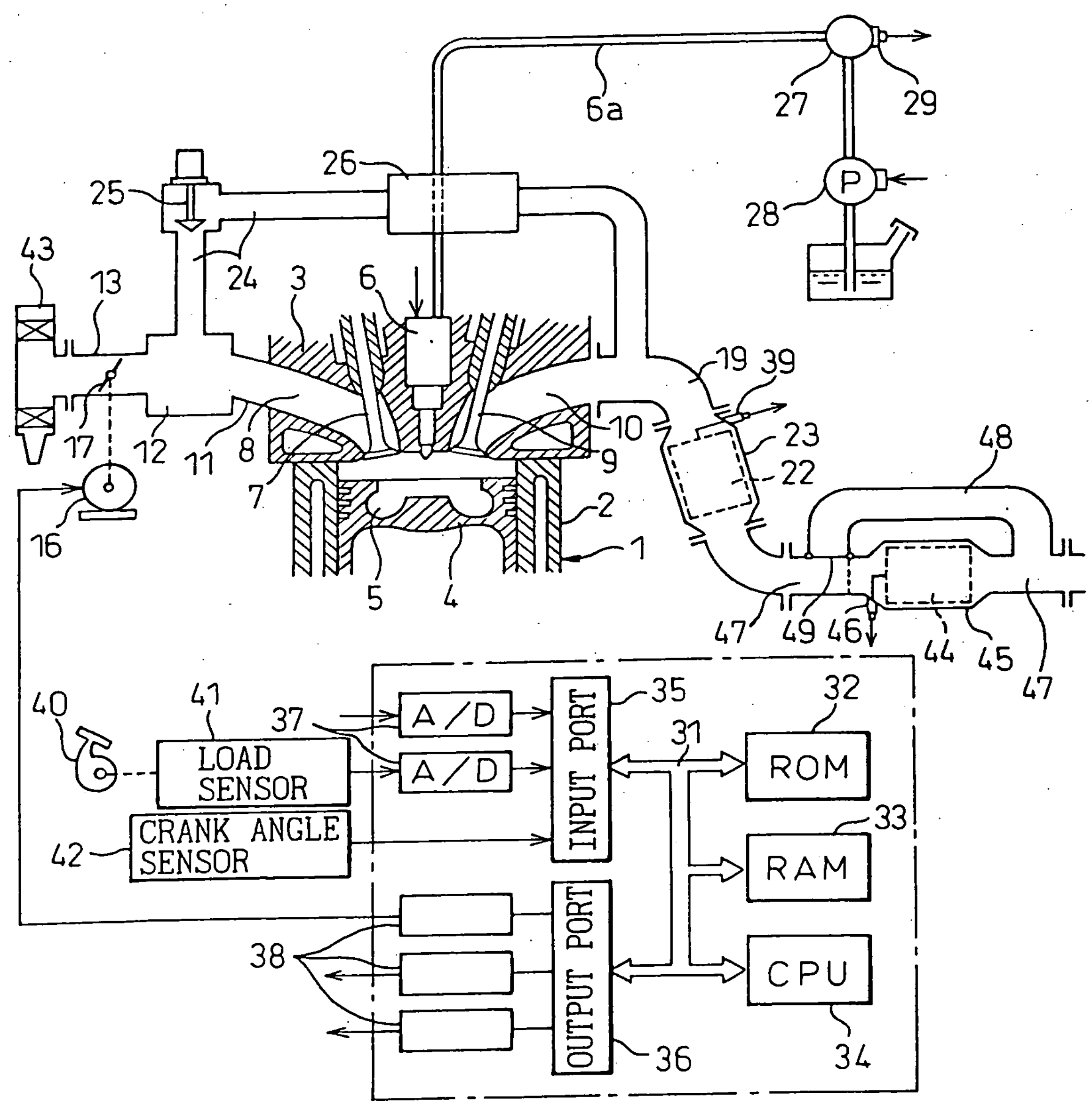
Fig.21



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CRANK ANGLE SENSOR
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Fig.22A

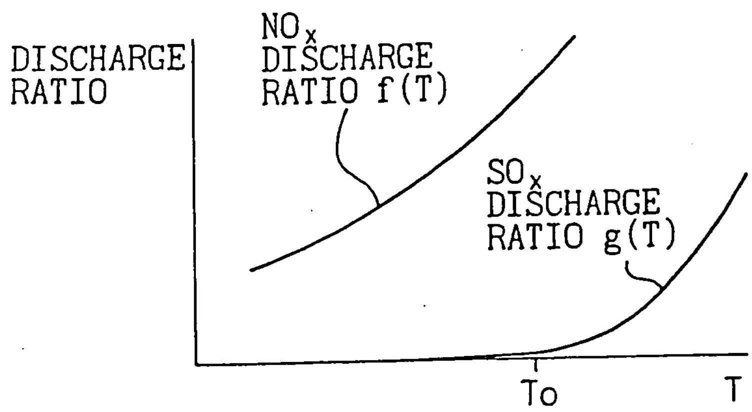

Fig.22B

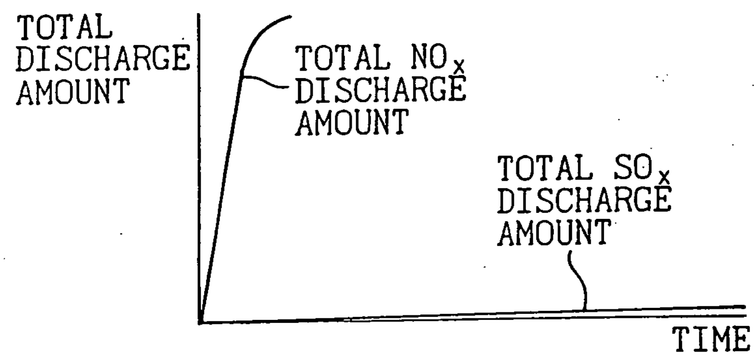

Fig.23

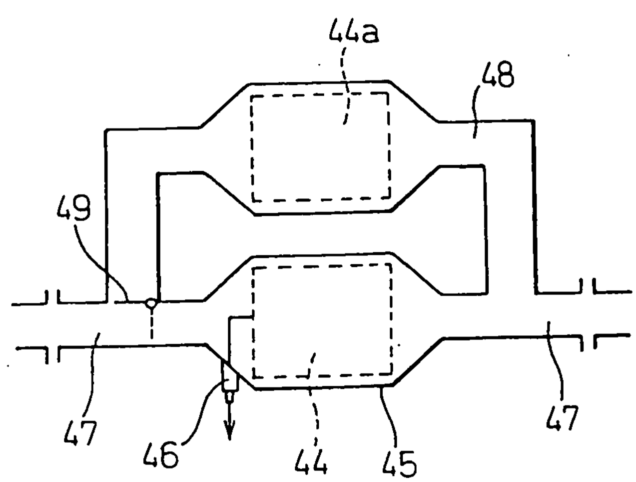

Fig. 24A

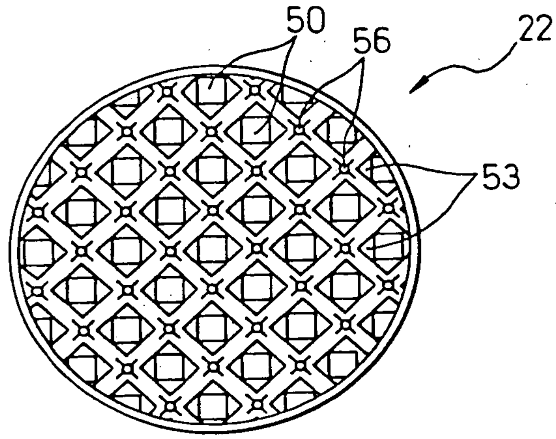

Fig.24B

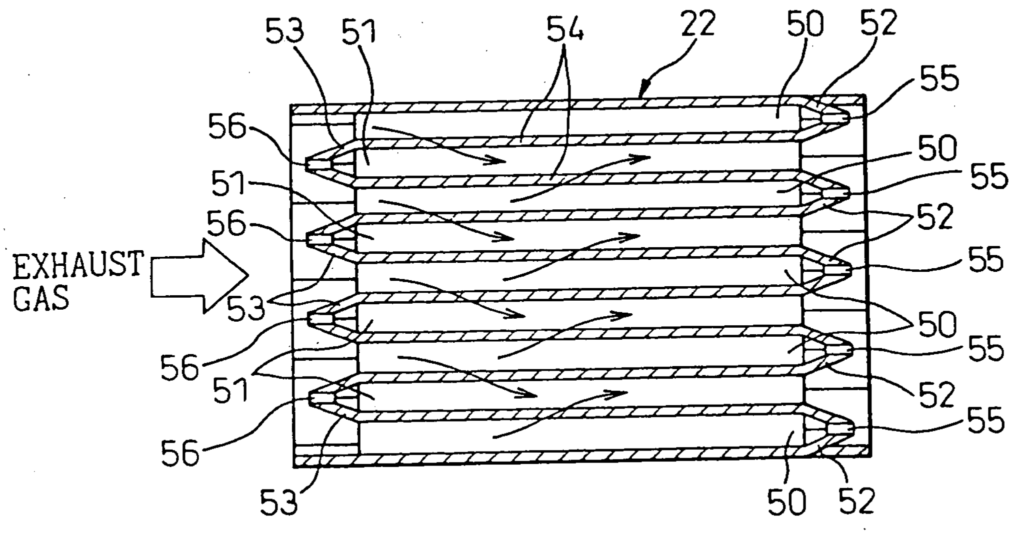

Fig.25A

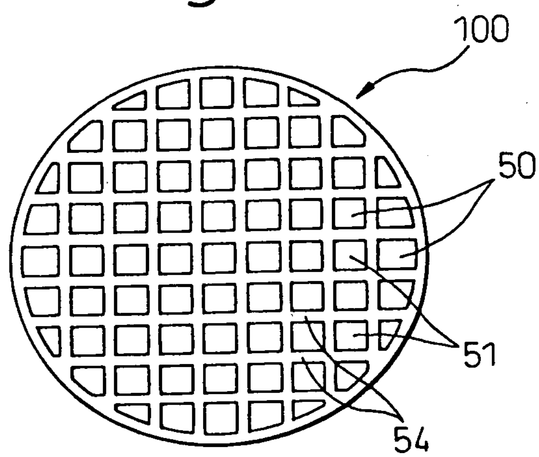

Fig.25B

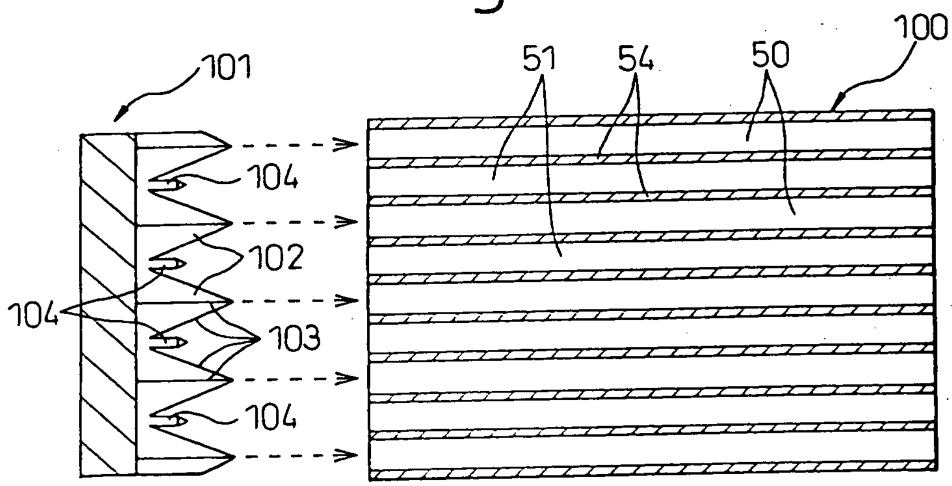

Fig.26A

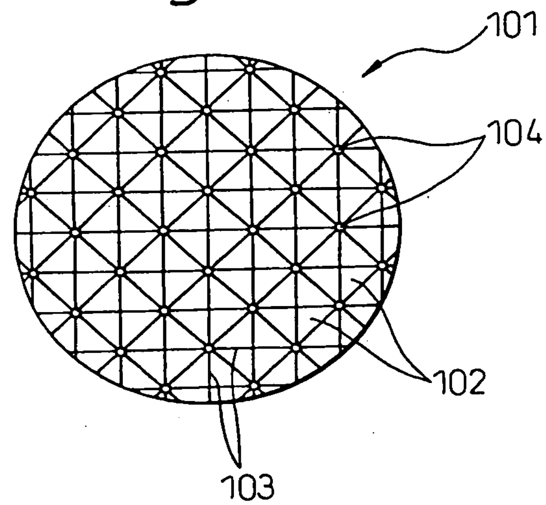

Fig.26B

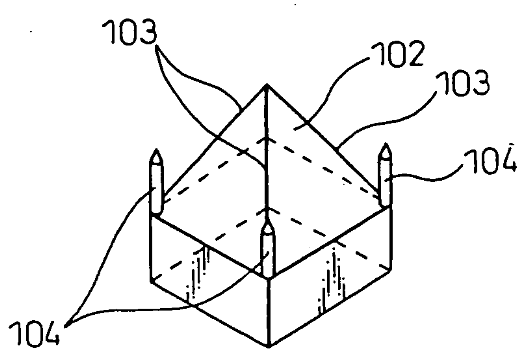

Fig.27A

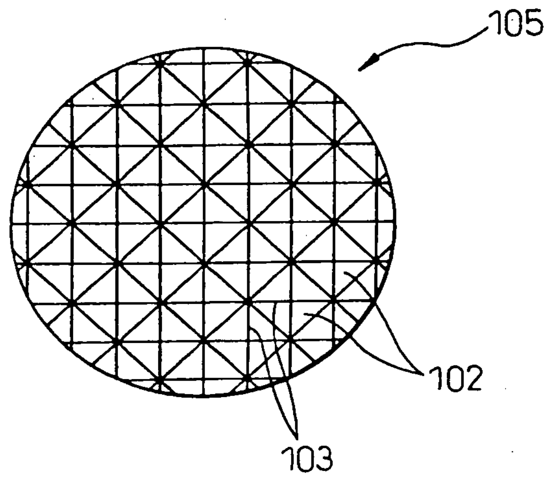

Fig.27B

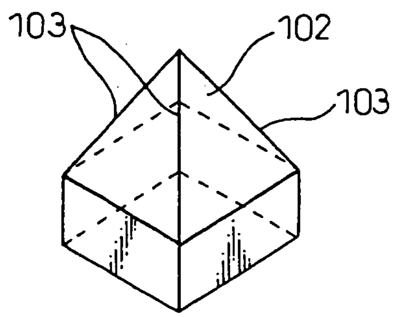

Fig.28A

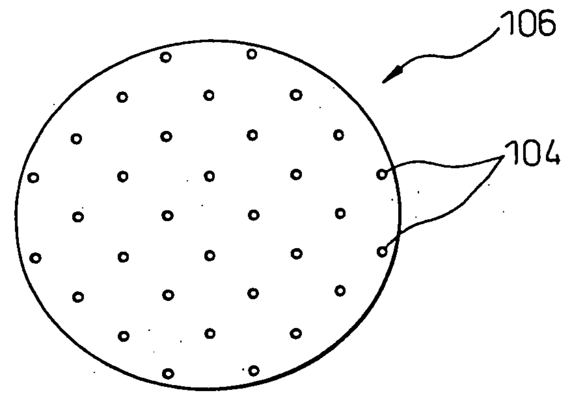

Fig.28B

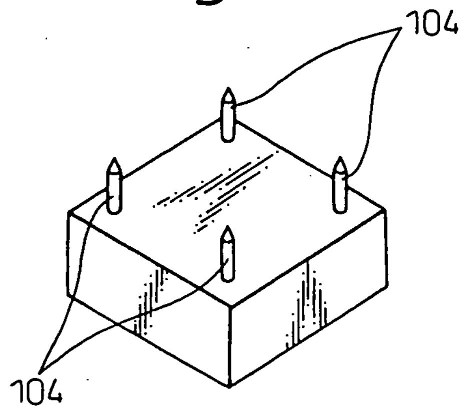

Fig.29A

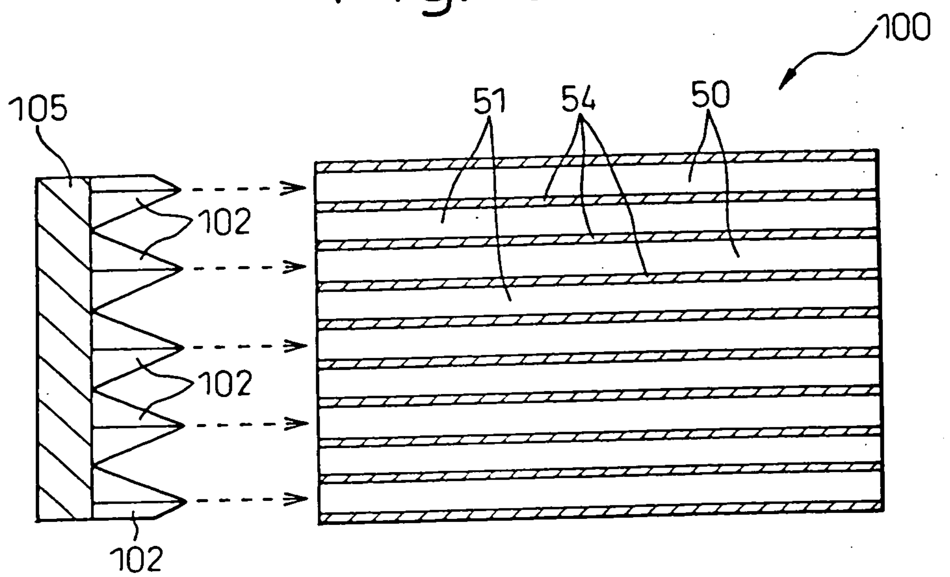

Fig.29B

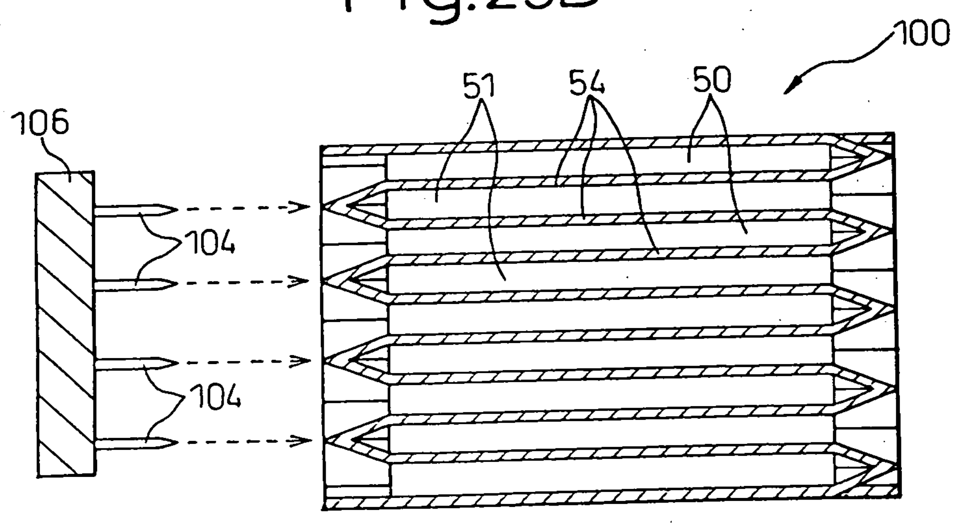

Fig.30

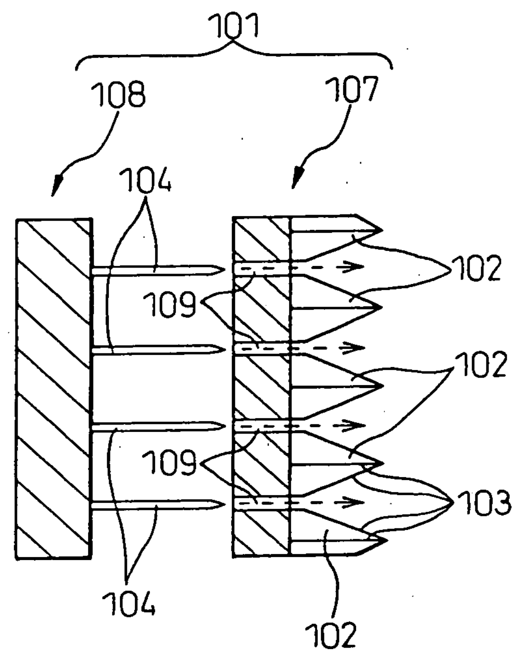

Fig.31

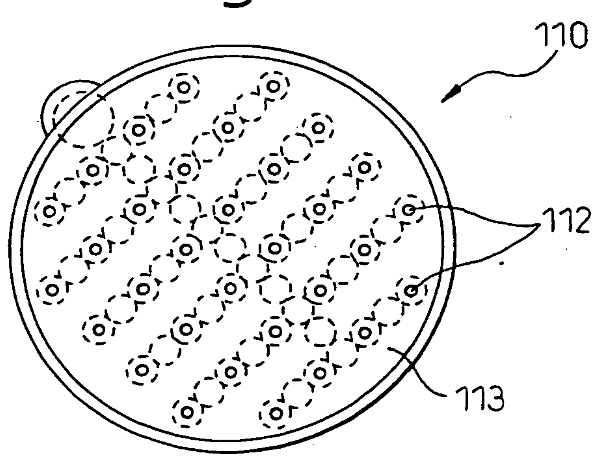

Fig.32A

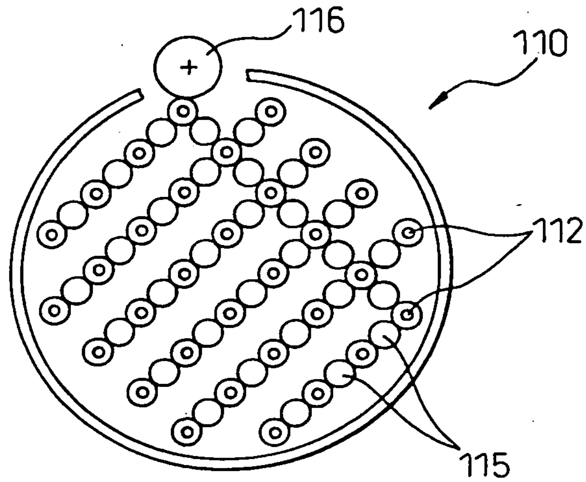

Fig.32B

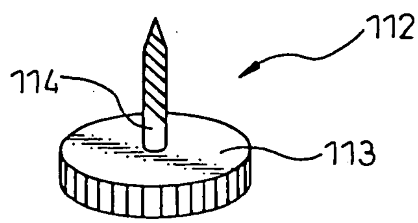

Fig.33A

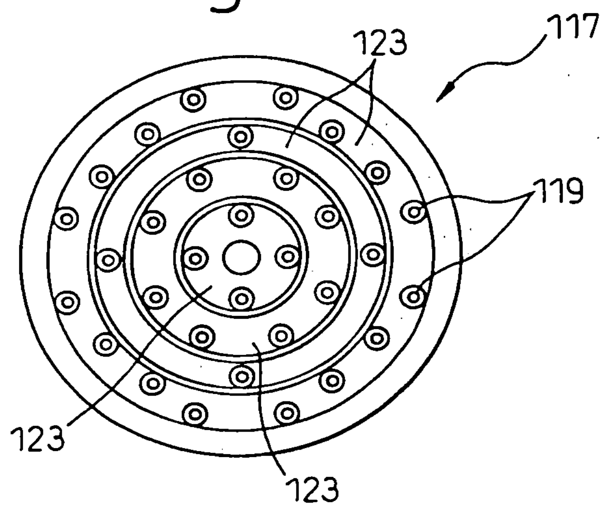

Fig.33B

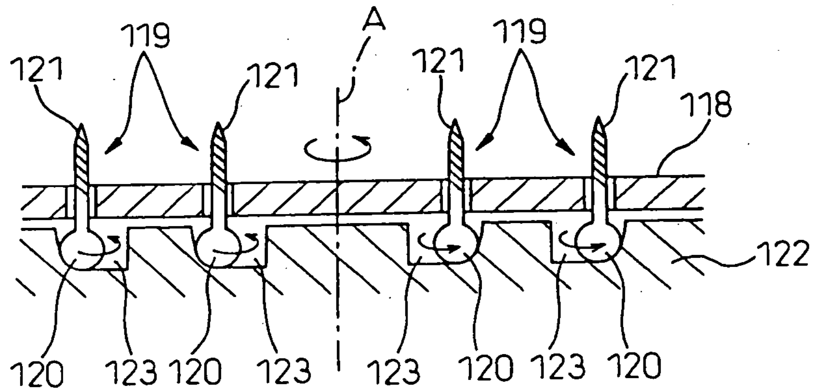

Fig.34A

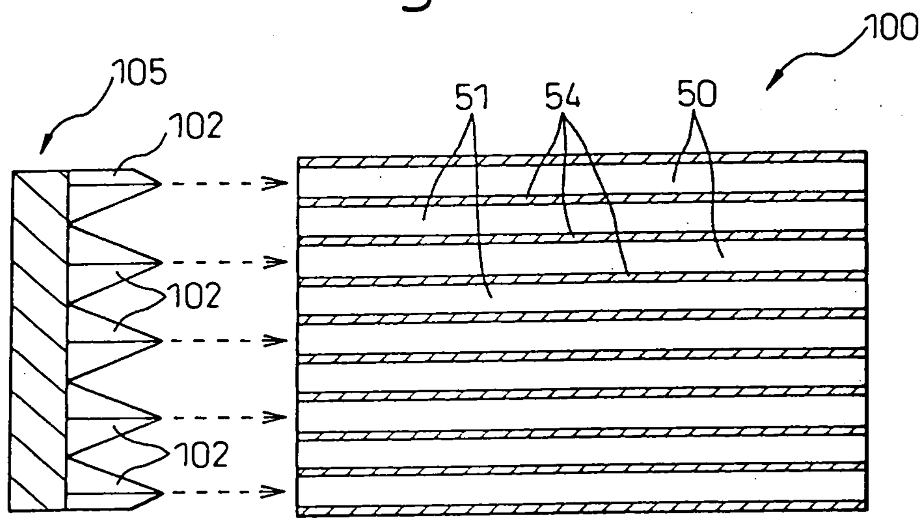

Fig.34B